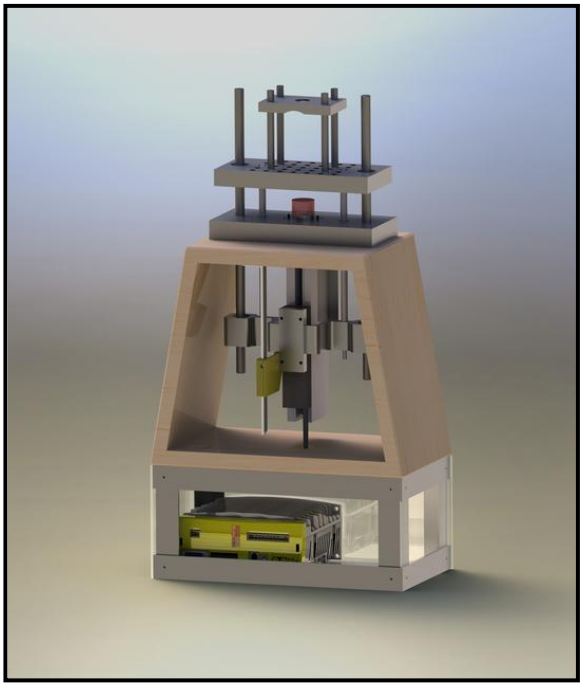
Sandia M.A.S.T.
(Miniature Automated Shock Tester)



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Senior Capstone Design Work
University of Idaho
Final Project Report May 10, 2012

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1. Executive Summary

For our senior capstone project, we have been tasked with designing a personal sized shock testing apparatus for Dr. Scott Whalen of Sandia National Labs. Shock occurs when two objects collide, causing rapid deceleration for a minute period of time. It is this impulse that Dr. Whalen wishes to measure so that he may test his proprietary electronics under these conditions. In order to accomplish this task we must first understand how to replicate these conditions with accuracy and precision, as well as how to modify them according to his user inputs. Sandia M.A.S.T. must produce shock waves within ranges of 1to 200 g's in magnitude and 1 to 10 milliseconds in duration. Dr. Whalen will then use this apparatus that we develop and subject his electronics to these conditions, testing their reactions and developing them accordingly.

Our proposal to date includes features prominent on current designs as well as other features that are unique to our design. We have determined that a dual-post shock tower with a drop table is the most appropriate for our client's needs. To actuate this device, a linear motor is to be used with the possibility of other solutions as a backup plan. With the accuracy we plan to incorporate into our design, Dr. Whalen will have a tool that exceeds his needs and allows him to develop electronics for Sandia National Labs well beyond the scope of this project.

A sub-group of our team has performed statistical analyses on the validity of our design features, with the additional motivation of being able to apply our senior design work to another class external of this project. This project has demonstrated to a 99% confidence level, that the viscoelastic damping effects will play a very significant role in comparison to impact velocity of the shock table. Through this experiment our math modeling experiments have been validated providing us with legitimate targets to shoot for in our conceptual designs and future work to be applied to this task.

2. Background

Safety protocol in Dr. Whalen's lab does not permit him to use any compressed fluids. A large majority of devices on the market use pneumatics for lift actuation as well as a system to reduce resonance. Additionally, a large majority of these are for applications where the device under test is well beyond 300 grams. Sometimes the capacity of the most basic tester is over 3300 pounds. Dr. Whalen has expressed the need for an electrically or an elastically actuated system to circumnavigate these constraints. With such a system, we feel that we will have greater controllability and reliability over other systems such as a gravity-fed drop, or a spring loaded system.

Complete data sheets for each system can be referenced in the appendix of the report.
Current competitor solutions include the following:

Figure 1 - Avex SM Series

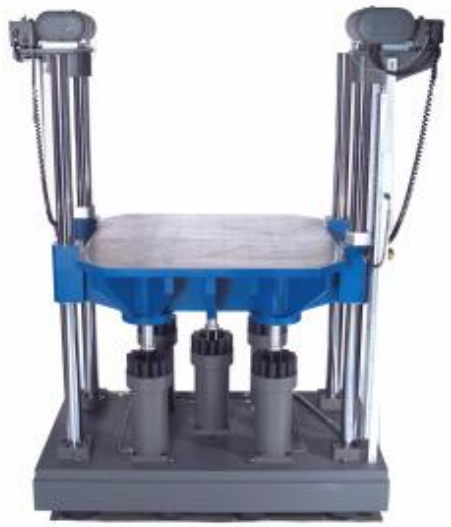
AVEX SM-105,110,220	
Shock Capacity	3- 30,000 g's
Shock Duration	0.012 [ms] to 100 [ms]
Desirable Capabilities	Able to produce three types of pulse shapes
Footprint Size	4 [ft^2] to 15.28 [ft^2]
Load capacity	50 to 200 [lbs]

Table 1 Avex SM Series Specs

LAB AutoShock II	
Shock Capacity	500- 600 g's
Shock Duration	2 [ms] to 65 [ms]
Desirable Capabilities	Safety interlock system
Footprint Size	5.33 [ft^2] to 20 [ft^2]
Load Capacity	600 [lb]

Table 2 LAB AutoShock Specs

Figure 2 - LAB AutoShock



Lansmount 152	

Shock Capacity	**400 g's**
Shock Duration	**2.5 [ms]**
Desirable Capabilities	**Lift actuation and release mechanism**
Footprint Size	**25 [ft^2]**
Load Capacity	**2000 [lb]**

Table 3 Lansmount 152 Specs

Figure 3 – Lansmount 152

Figure 4 – LAB SD Series

LAB SD series	
Shock Capacity	**1000 g's to 3500 g's**
Shock Duration	**0.3 to 1 [ms]**
Desirable Capabilities	**Gravity actuation, small footprint.**
Footprint Size	**0.694 [ft^2] to 2 [ft^2]**
Load Capacity	**500 to 3300 [lb]**

Table 4 LAB SD Series Specs

3. Problem Definition

A concise table of needs, specs, and targets can be viewed in Appendix A. The design will be reliable and compact, capable of measuring shocks up to 200 g's over a range of 1-10 milliseconds, compliant with safety

considerations, and will be designed for 5 or more years of performance. The device will be electrically powered and will take user input to deliver precise impulses to the device under test, while monitoring the output through LabView software. Resonance will be mitigated.

4. Project Plan

Team responsibilities are delegated amongst the team. The following is a list of roles and responsibilities of each team member.

Team Lead: **Cameron Hjeltness**
- Send out reminders for events, action items
- Create meeting agendas
- Run and schedule meetings
- Manage timeline
- Coordinate with POC for client meetings
- Coordinate with documenter for monthly status reports

Budget Manager: **Travis Nebeker**
- Keep a record of expenditures
- Maintain a current balance of team funds
- Communicate with UI Department Manager
- Communicate with team about purchases
- Responsible for tracking orders
- Responsible for resolution of conflict with suppliers

Webmaster: **Fernando De La Garza**
- Maintains up to date status of project
- Designs and manages team website
- Responsible for website deadlines and content
- Generates team blog

Documenter: **Michael Brewster**
- Takes meeting minutes
- Maintains team project binder
- Digital file organization
- Check documented team deliverables
- Maintain team monthly reports
- Maintain confidentiality and legality of documentation

Point of Contact: **Nicholai Olson**
- Maintain contact with; Mentor, Client, Advisor
- Facilitates smooth information flow between parties
- Relays client communication to team members and vice-versa
- Notifies client on team progress

A current project timeline is shown in Appendix B.

5. Concepts Considered

5.1. Design Breakup

Initial talks with our group concluded with eight different categories that we felt were the most important criteria for the shock tester (Table 5).

Table 5 - Morphological Chart

STRUCTURAL	FOUR POST VERTICAL	TWO POST VERTICAL	SINGLE POST	NO VERTICAL STABILIZATION	
REDUCTION OF ENERGY LOSS	BEARINGS	BUSHINGS	NONE		
TABLE LIFT ACTUATION	CABLE & WINCH	ACME SCREW	LINEAR MOTOR	ROTARY MOTOR AND BELT SYSTEM	NONE
RELEASE MECHANISM	ELECTRONIC CLUTCH	SOLENOID & PIN	MOTOR CONTROLS	NONE	
EXTERNAL SOURCE OF ACCELERATION	SPRINGS/ ELASTIC MATERIALS	ROTATIONAL HAMMER	LINEAR MOTOR	ROTARY MOTOR AND BELT SYSTEM	NONE (GRAVITY)
METHOD TO VARY LEVEL OF SHOCK	VARIABLE ELASTIC INPUT STIFFNESS	DROP FROM VARIOUS HEIGHTS	MOTOR/SOLENOID CONTROLS	VARY STIFFNESS OF BASE	
ENERGY DISIPATION (After impact)	VISCOELASTIC DAMPERS	LOCKING MECHANISM	MOTOR/SOLENOID CONTROLS	SOLENOID	ELECTROMAGNETIC STOPPER/LIFT
CONTROLS	LINEAR ENCODER	CONDUCTIVITY IN COLLISION	INDUCTANCE BASE VELOCITY SENSING		

Category selection was based on necessary functions of current market offerings that we researched. Systems were broken down into mechanical, electrical, and electro-mechanical classifications. From this point we further divided the systems into quantifiable, single function categories. Safety standards as defined by Sandia National Laboratories restricted the team from exploring options involving pressurized fluids (i.e. hydraulics and pneumatics). Many shock testers on the market employ the use of high pressure fluids to lift and/or accelerate the drop tables (Figure 5). This made market research on force input only marginally helpful.

Figure 5- Pneumatic Shock Testing Apparatus

5.2. Testing Configuration

Our group had to decide on form of our shock tester before we could quantify options to be considered. We were provided limited spatial constraints (Appendix A) that caused our group to lean to a vertical drop device. Based on our market research, a vertical drop was unanimously chosen. The final factor that helped our group decide on a vertical structure was gravity. With a vertical design, gravity would help in acceleration of the drop table, if not provide the primary means of acceleration.

5.3. Structural Considerations

Based upon research of competitors in the market, the structural design of the shock tester was limited to three categories, first being a four post design. This design is extremely stable, and strong. This allowed the reduction in diameters for the posts while keeping the strength that other designs may possess. Although a four post is stable, it would take longer to machine, and would also cost more than other design considerations. The table and posts would need to be perfectly square to keep the system from binding. Another consideration was the single post design, which was a less viable idea due to reliability and structural issues, but allowed team members to compare ideas during the decision process (Figure 6). The platform that held the DUT would have to be balanced to prevent from binding while being lifted and dropped for the shock. The third idea that was presented was a two post design, which most of the competitors used based on our preliminary market research (Figure 6). This design is sturdier than the single post, and will have less friction than the four post. These design considerations were incorporated in our morphological chart and house of quality, as is the case for all categories discussed below.

Figure 6 - Single Post Design

Figure 7- Double Post Design

5.4. Reduction of Energy Loss

A major concern with respect to our design was reduction of friction between the posts and the drop table. Our team researched several options to mitigate this loss. Options considered included no device, linear ball bearings, and linear bushings. The use of bushings and bearings were both valid options for a guide rod based structure, and only differed in price, percent friction reduction, and working load rating.

5.5. Lift Actuation

With a drop table, there must be a lift mechanism to re-set the drop table and gain the potential energy necessary. There were a considerable number of ideas for this function, one of which being a cable and winch. Although this would be easy to control with LabView, it would be mechanically complicated. Another great idea presented was the ACME screw (Figure 8). This screw would allow the table to lift and then to drop. Although this design idea is easy to build and would be cost effective, it would need a coupling release mechanism and would only use gravity for the drop. The acceleration would be dependent upon the amount of friction that is experienced from contact with the posts, which will likely vary. The third idea presented in the morphological chart was a rotary motor and belt system. This design is not accurate, although cost effective, and would rely upon the mechanical advantage of a pulley system to provide acceleration.

Figure 8 – ACME Screw

The last idea, a linear motor, is the most expensive but highly accurate. The linear motor will not only be able to lift the table, but accelerate the table downwards because of the ability to move in either direction with motion specified by the control system. For this option a linear encoder would likely be used. A sensor reads a magnetic strip, which allows the computer to recognize the linear motor's displacement. The above options are dependent upon the control program that we will develop for LabView, and supply to our customer per requirements (REF Appendix A).

5.6. Source of Acceleration

Once the drop table is at its desired height, it becomes necessary to accelerate to a specified velocity to impart the desired shock. The shorter the distance, the greater the acceleration needed. To create this acceleration several options were considered. These included the use of only gravity, elastic materials, a rotary hammer, a linear motor (as stated section 5.5), a solenoid, or a motor and belt system. Advantages of gravity and springs/elastics included cost, simplicity, and availability but were lacking in repeatability. The use of a linear motor had several advantages, including the ability to accurately control and have constant feedback, as well as the elimination of several other systems, but was the most expensive option by a fair margin. For all practical purposes the option of using a solenoid system was the same as a linear motor, with the exception of being cheaper. A rotary motor and belt system would be less reliable and more mechanically complex.

5.7. Shock Level and Energy Dissipation

Although pulse shapes were not a part of the project specification, Sandia M.A.S.T. wanted to pursue this as an option in order to go above and beyond. From the Senior Lab team's results based on the comparison of drop height and viscoelastic materials, they concluded that damping materials between the table and the stopper during the shock were heavily significant to the shock peak and duration (REF Appendix C). The team used packaging foam, approximately 3mm thick per sheet, to soften the impact between the slider, where the accelerometer was mounted, and the stopper. By reading voltage charts between one and two pieces of foam, the team was able to change the pulse shape from a sharp parabolic graph to very soft sinusoidal graph (REF Appendix D). This along with changing the drop height changed the duration and amplitude of the shock. Locking mechanisms were presented to dissipate the energy, but the team believed that ringing was a problem.

6. Concept Selection

The first and most fundamental design decision was that of how to orient the shock tester and how to generate the required shock. Several options were considered for this function. One idea consisted of having a horizontal sliding base that would impact against a stationary wall. Another idea was to have a stationary base hit by some sort of heavy device such as a hammer. Yet another concept consisted of a vertical tower with a sliding table that would impact a stationary base at the bottom. The structure and orientation decision matrix can be seen below (Table 6).

	WEIGHT	FOUR POST VERTICAL	TWO POST VERTICAL	SINGLE POST VERTICAL	HORIZONTAL SLIDER	STATIONARY BASE AND HAMMER
COST	20	5	3	5	3	3
MACHINABILITY	40	1	3	5	5	3
ROBUSTNESS	30	3	5	3	3	3
REPEATABILITY	50	3	5	1	3	1
DESIGN LIFE	40	3	5	5	3	3
SIZE	40	5	5	5	1	1
	TOTAL	500	780	640	620	440

Table 6 Decision Matrix for test apparatus structural orientation

From the decision matrix, it was determined that the two post vertical drop table would be the best option. The four post design would be more difficult to manufacture and would have the potential for binding since there would be the posts have the possibility of being misaligned. A single post option was deemed to not be repeatable enough since it would be hard to keep it oriented the same way for each test. The horizontal slider option was deemed to have too large of a footprint. The stationary base and hammer option would likely have more resonance problems and in addition would likely have a shorter life because key components would be subjected to higher shocks than in the other options.

After it was determined that a vertical tower would be used, it was then required to find a way to create the table motion. Ideally, an actuation method would be easy to integrate into the design, provide high controllability, and would be relatively inexpensive. Several options were considered and the results were compiled into Table 7 below.

	WEIGHT	CABLE & WINCH	ACME SCREW	LINEAR MOTOR	ROTARY MOTOR & BELT	SOLENOID
COST	40	5	3	1	3	3
CONTROLLABILITY	30	3	3	5	1	5
EASE OF INSTALLATION	20	1	3	5	1	3
STRENGTH / RELIABILTY	40	3	5	5	1	5
SAFETY	30	1	3	5	3	3
	TOTAL	*460*	560	640	300	620

Table 7 Table Actuation Decision Matrix

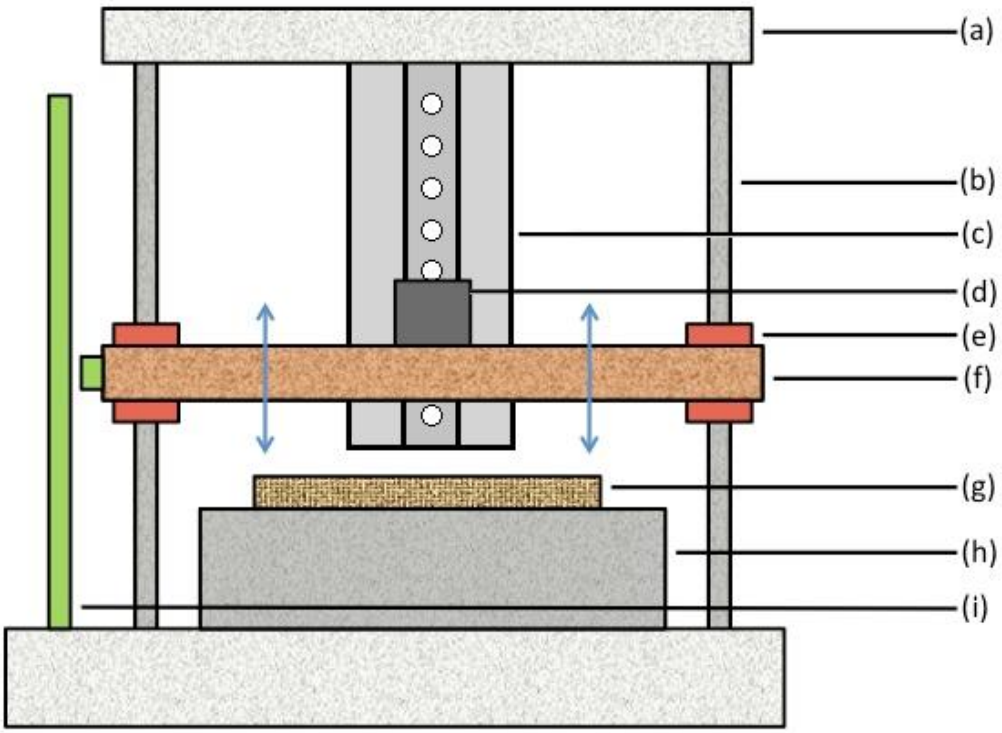
The linear motor and solenoid options scored the highest due to their high controllability, ease of installation, and reliability. The cable and winch option and the rotary belt and motor option scored very low due to complexity and reliability issues. The ACME screw option had a relatively high score but the major drawback of this option was its complexity due to the many extra components that it would need. Another benefit of the linear motor and solenoid options is the fact that they require no additional components to create a downward force in order to impart shocks of the required magnitudes. These components can be easily programmed to produce different shocks. In contrast, all of the other options would likely need spring systems to create a downward force or require additional height.

In an attempt to minimize size and complexity of the system, linear motors or solenoids will be used for table actuation. We hope that this decision will also help increase the system reliability and life with less components to fail and wear down with use.

7. Mechanical System Architecture

The structure of the testing apparatus will be composed of a two-post vertical drop table. A detailed sketch of the conceptual design is shown below in Figure 9. Component (a) refers to the support structure of the testing apparatus to provide rigidity for the structure as a whole. Component (b) is a pair of guide rails specified from Thomson. These guide rails are to be precision machined and press fit into the top and bottom supporting structure for additional rigidity. This design will be machined with tight tolerances to reduce friction loss and prevent any binding in the bearings (e). (c) is a linear motor which imparts the force to the drop table. Component (d) is the device to be tested by the apparatus and it is mounted to the drop table (f). The device to be tested (d) will also include an accelerometer mounted to it. This accelerometer will measure the shock that the device is subjected to. An additional sensing unit, the linear encoder (i) will provide feedback of the drop table motion. Component (g) is the damping material to lessen the vibrations associated with the drop table impact, while (h) is the damping material mount.

Figure 9 Conceptual drawing of the shock tester



8. Electrical Systems

The control system architecture can be seen in figure 10. The system consists of a host computer, a motor controller, a motor with Hall Effect sensors, and a linear encoder. In addition, there is a data acquisition module will record the output from the accelerometer.

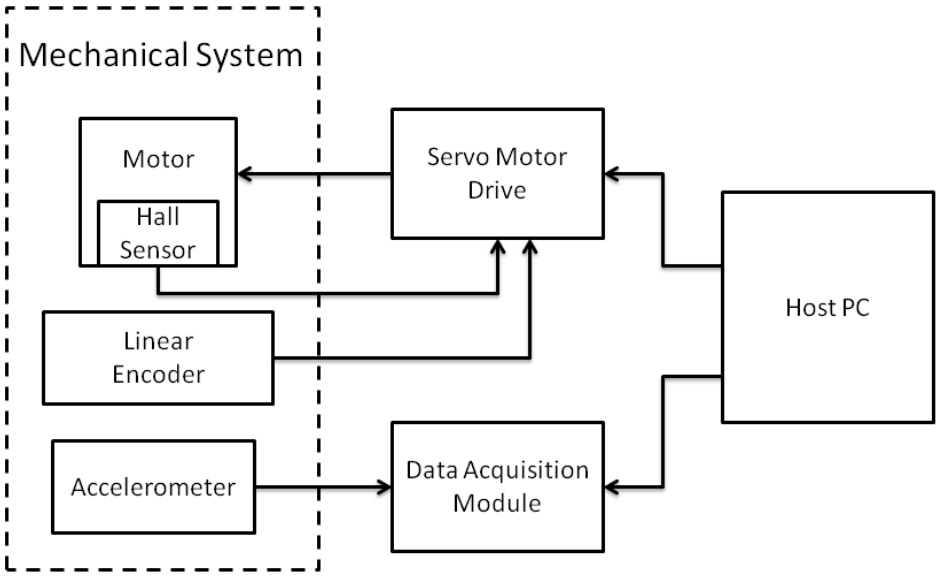


Figure 10 System Overview

During a test, the control system will first raise the table to a defined position. It will then accelerate the platform to a desired impact velocity and disable the velocity control shortly before impact. After the impact the controller will once again be enabled to position the platform back to the starting point in preparation for the next test and to avoid any secondary shocks.

The systems uses a Balder Microflex e100 motor controller as the linear motor controller. The controller is an off-the-shelf controller that takes in signals from the hall effect sensor mounted on the motor as well as a differential linear encoder to control the motor position. The linear encoder is a custom mode module designed for the apparatus using an Austria microsystems AS5306A magnetic linear encoder chip.

The linear encoder module has 15 micron resolution and a differential quadrature encoder output. A Data Translation DT9812A was used for the data acquisition.

8.2 System Operation Procedure

Step 1) Install Labview (download evaluation version)

Step 2) Install drivers

Step 3) Install Open Layers library (from DAQ manufacturer)

Install LV-Link (from DAQ manufacturer)

Step 4) Set up Ethernet adapter

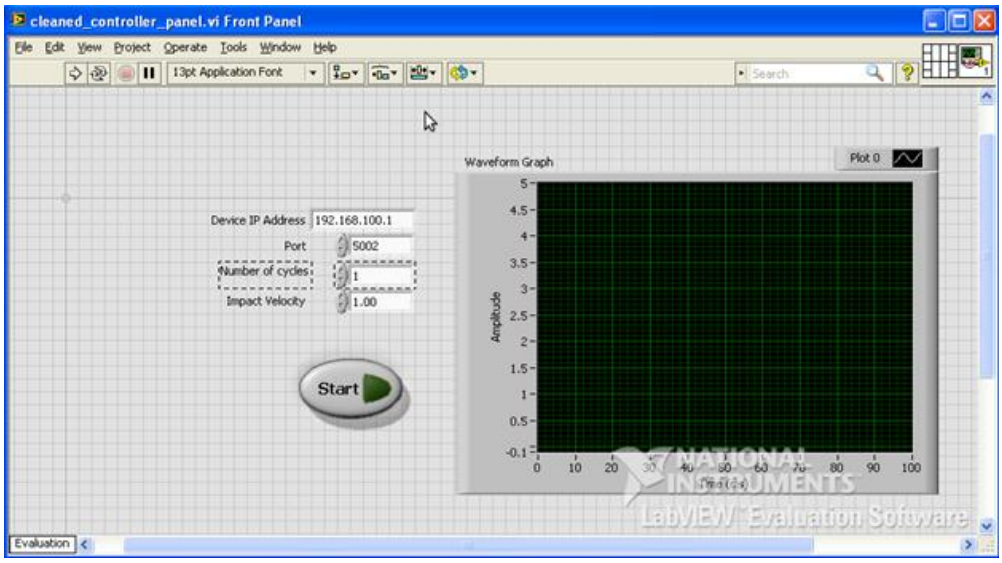
Step 5) Plug in power cord to wall and into power plug in on back of device

Plug in Ethernet cord.

Step 5) Open and run given Labview program

Step 6) Input device address, number of cycles, desired impact velocity

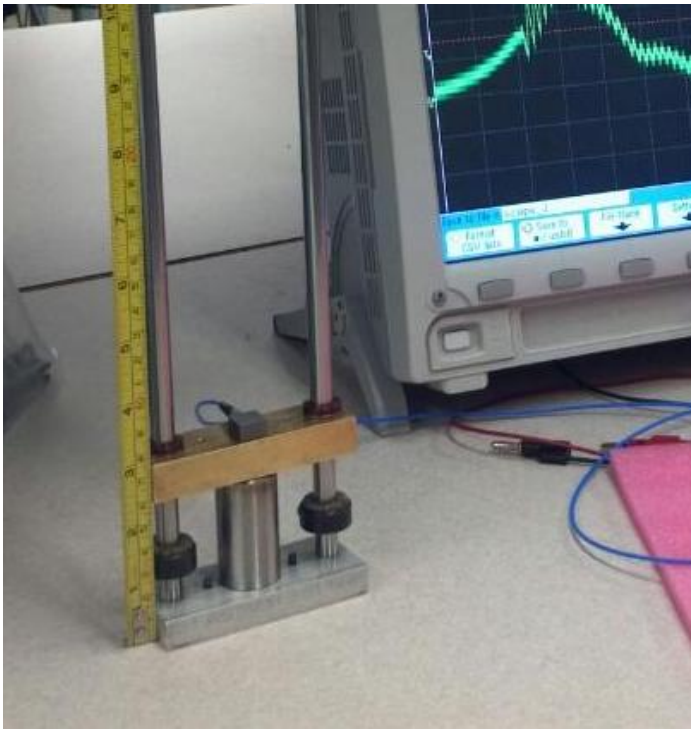
Hit the Go button



9. Detailed Design

9.1 Initial Prototyping

During the prototyping phase of the project, we developed a series of models that helped us design the final shock tester. The first was a large steel structure built to gain an initial understanding of the process. It was constructed with ample vertical height to allow modifications as necessary. Unfortunately, assembly tolerances were very loose, creating noise in the accelerometer responses and did not provide results that could be analyzed for peak accelerations and shock duration. From this design, we did learn however that a minimal height was needed, rather than over 3 feet of vertical drop. This in turn, helped to initially validate our math model.

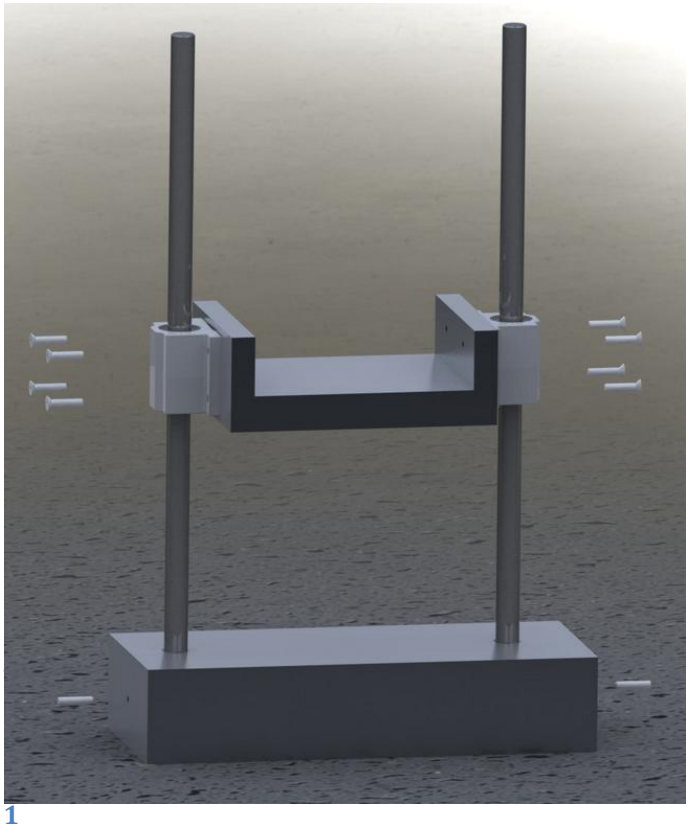


Our math model was further validated after moving to our next prototype, a spring-mass-damper test fixture from a previous class. It was

much smaller in size and built with precision rods and linear bushings. With this upgraded set of features, we obtained cleaner data with significantly less noise. We were able to determine statistical significance of the relationship between damping materials used and drop height applied.

Figure 12 Last Prototype

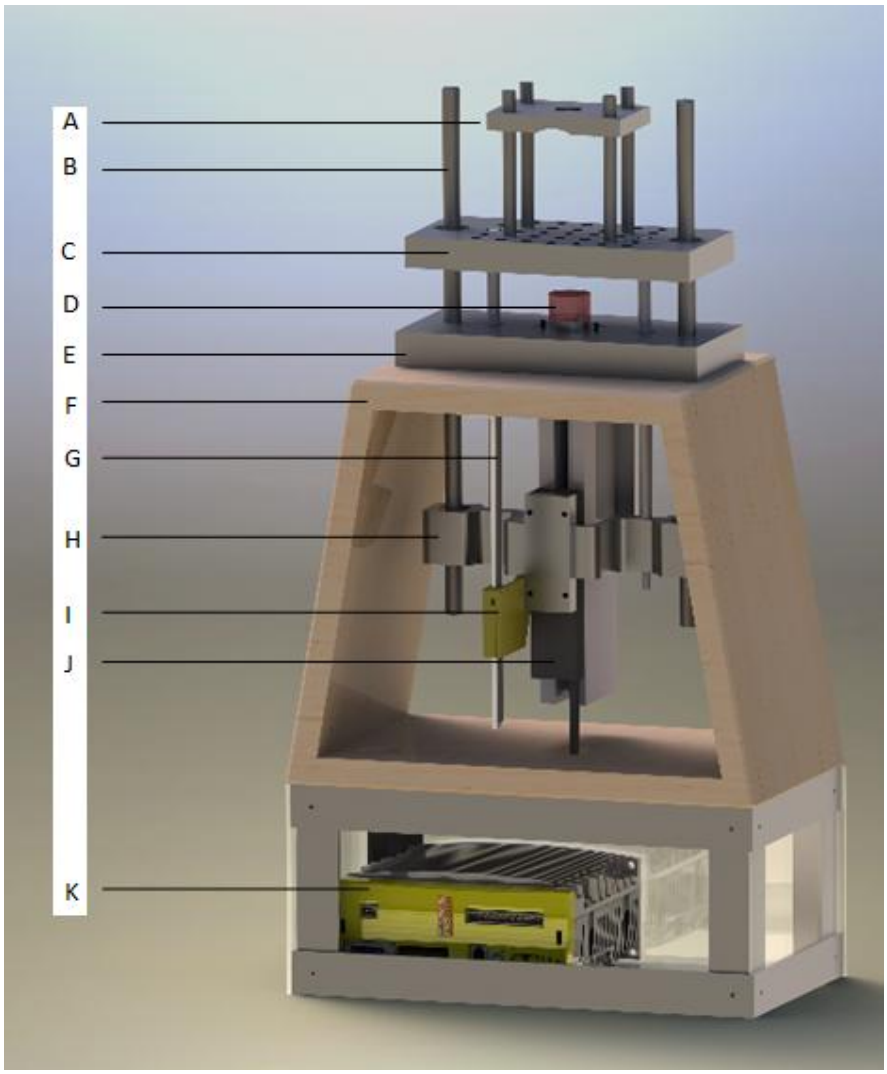
The last prototype developed had an aluminum base, precision rods, and linear bushings much like the second prototype. It was larger and more like the proposed final design. This design helped us map our machine plans in simplifying the process and to realize that we needed higher tolerances. In the end we used portions of this design on the final product. These components included high precision Thompson rods and the impact base.



1
3 Last Prototype

9.2 Final Assembly

The final design is shown in Figure 14. There is a large degree of similarity to Figure 9 displaying our conceptual design. (A) shows the DUT fixture which mounts to hole pattern as specified by Sandia Labs. (B) represents the Thomson rods, allowing (C), the drop table, to slide smoothly with a high degree of mechanical tolerance. (D) is the damping material mounted to component (E) which is a component derived from our third prototype. (F) is our wooden base, constructed of maple hardwood. (G) shows our linear encoder which relays information of the table's position to within 15 micron to component (J), the linear motor. (J) is regulated by (K), the linear motor controller. Our specifications for the design were provided by the client and served to guide our design from beginning to end. Listed with a description, they are in the following table.



GENERAL NEED	SPECIFIC REQUIREMENT	TARGET VALUES
Physical constraints	Small Size	Maximum base dimension of 30" square and height of 72".
	Standardized mounting interface	1.5" center 3/8" -16; course thread
	Standardized DUT to contain proprietary electronics	Cylinder of diameter 5 cm, length 8 cm, mass of 0.3 kg.

	Electrical Energy Input	120 V AC Electric Motors, Solenoids, etc.
Instrumentation	Measure shock in X direction	100g's to 200g's
	Measure shock in Y direction	100g's to 200g's
	Measure shock in Z direction	100g's to 200g's
	Voltage response will be measured upon impact.	0 to 10 Volts
	Shock and voltage response monitored	LabView Software; High bit rate data acquisition device
Performance Requirements	DUT must not experience ringing.	Single pulse half sine wave.
	Accurate	Calibrated to Input Correct Levels of Shock
	Repeatable	Perform numerous similar tests with consistent results
Safety/Robustness	Pinch Points Protected	Physical Shielding
	Electrical Connections Protected	No exposed wiring or electrical components
	Long life	Perform several hundred tests per month for a desired life of five years.

10. Conclusions

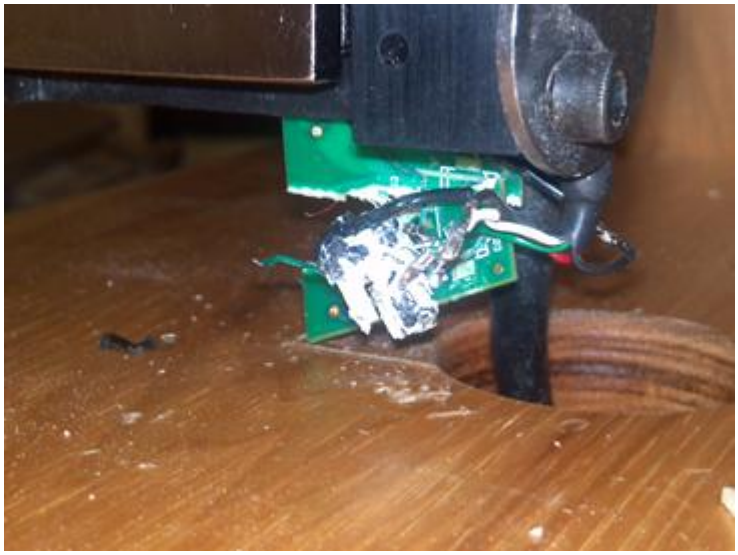
The goal of this project was to provide Sandia Labs with a reliable mechanical shock tester for their proprietary electronics within the operating conditions of 100 to 200 g's and limiting the applied shock to within 10 milliseconds. While not the most complex task, this design posed many challenges of its own that proved to be a good resource for future knowledge. Machining some of the components such as the arm that mounts to the linear motor to transmit the force through the dual steel rods were tricky, requiring a detailed machine plan and the know-how to deriving the correct geometry within tolerances. The electronic systems proved to be more complex than originally planned, with many various parts. Designing and fabricating the linear encoder boards involved large amounts of time planning each component.

Overall, the project's goals were certainly met. The accelerometer mounted to the surface of the device under test registered shocks within 175 g's which is within 12.5% of the intended upper range of operation. The size was limited to be as small as reliably possible. This was not an explicit design constraint given to Sandia MAST, however from talks with the client and other specs given, it was evident that size was an issue. Physically the shock tester was required to stay within 30" wide by 30" long by 72" tall. The end design captured much less territory with dimensions of 14" x 7.75" by 22". In achieving the end-goal of this project, Sandia MAST has capably demonstrated that a mini shock tester is viable and produced a working model from which further designs can be fabricated.

Recommendations

Short-Term Recommendations for Sandia National Labs are as follows:

1. Replace the Hall-effect sensor board as seen in **Appendix L**.



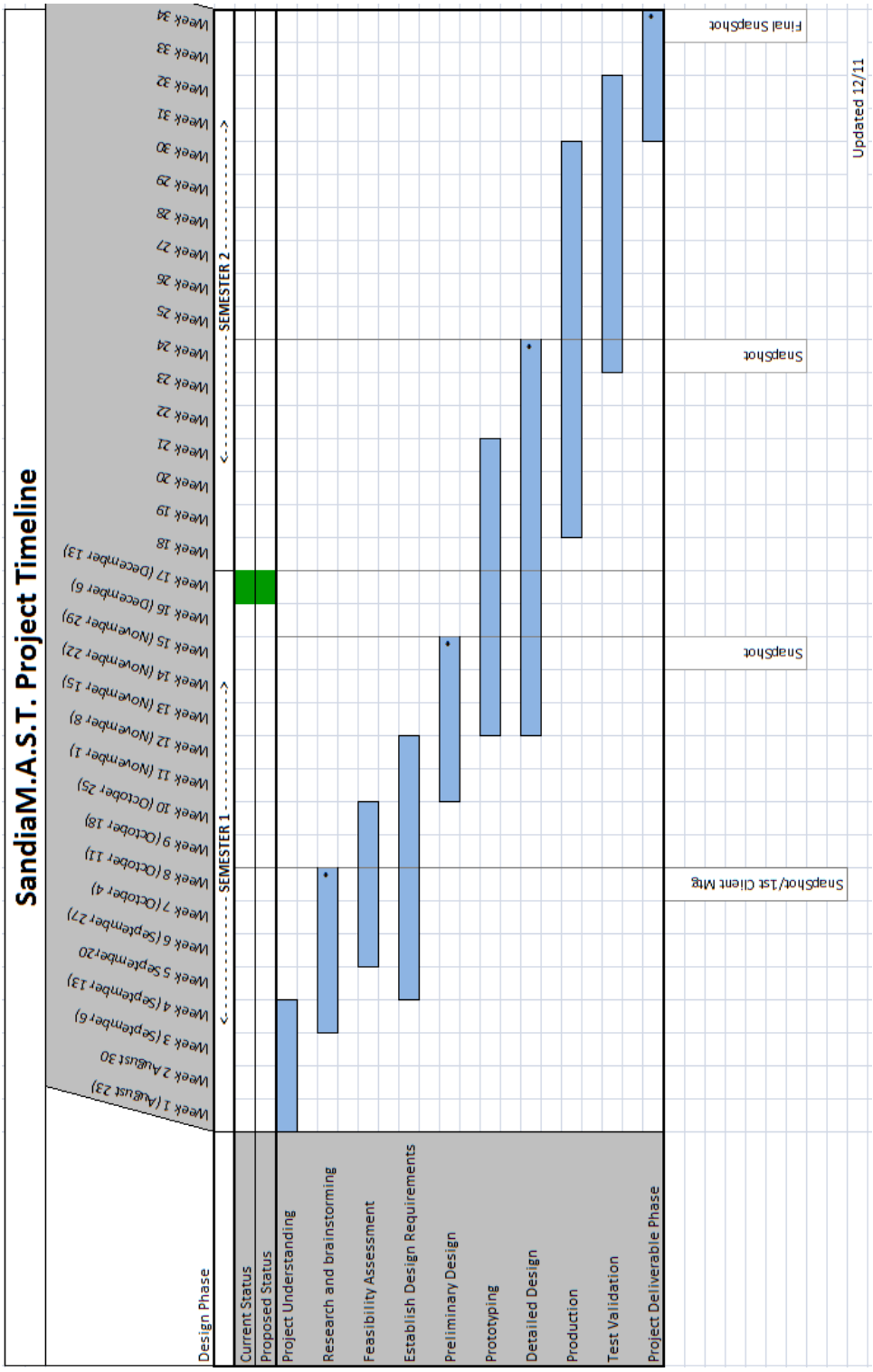
2. Fabricate more damping samples per manufacturer's instructions in **Appendix G**.
   2.1. Use damping caster and bases.
3. Re-fabricate damping caster and bases per drawing package. The old ones were discarded accidentally.
4. Never operate without damping sample.
5. Install photo-gate interrupter to avoid crashes into underside of aluminum base on the up-stroke.
6. Mill slot into base to include clearance for Hall-effect sensor.

Long-Term Reccomendation for Sandia National Labs are as follows:

1. The shock tester must be mounted to a solid workbench table to reduce noise.
2. Lubricate Thomson rods with graphite powder as necessary.
3. Provide adequate safety measures to ensure no injuries are incurred during operation.
4. Do not operate without plexi-glass panels installed.
5. If disassembled, reassemble with blue Loctite on all metal-to-metal fasteners.

11. Appendices

11.1 Appendix A (Project Timeline)



11.2 Appendix B (Statistical Significance of each factor)

ANOVA : Peak Response

Source	dof	MS	Fo	Fcrit	Sig?
A	1	20606.24	523.8537	4.12	*
B	1	277913.6	7065.143	4.12	**
AB	1	1324.709	33.67687	4.12	*
Error	36	39.33587			
Total	39				

ANOVA : Pulse Duration

Source	dof	MS	Fo	Fcrit	Sig?
A	1	1.922	33.26538	4.49	*
B	1	183.618	3178.004	4.49	**
AB	1	1.682	29.11154	4.49	*
Error	36	0.057778			
Total	39				

Key
* - Significant
** - Very Significant

11.3 Appendix C (Experimental Pulse Data)

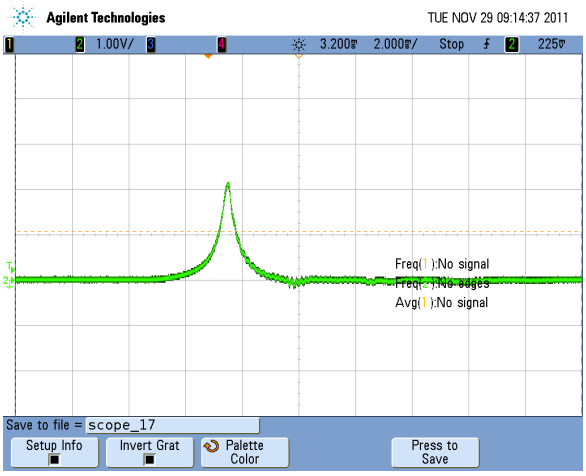


Figure 11: Drop Height: 8.5 cm
Damper Thickness: 3 mm
Peak Acceleration: 210 g
Pulse Duration: 3.7 ms

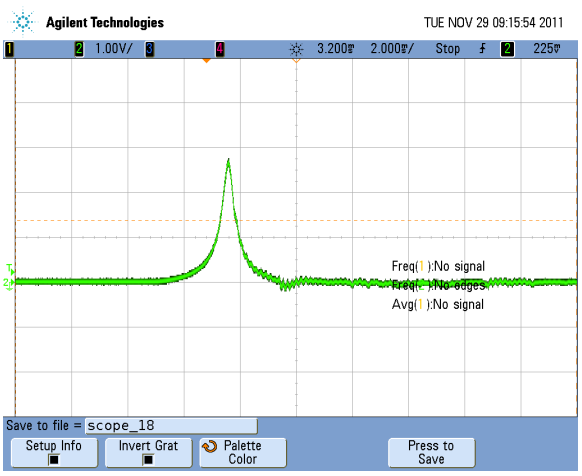


Figure 72: Drop Height: 15.5 cm
Damper Thickness: 3mm
Peak Acceleration: 272 g
Pulse Duration: 3.7 ms

Figure 83: Drop Height: 8.5 cm
Damper Thickness: 6 mm
Peak Acceleration: 51 g
Pulse Duration: 11 ms

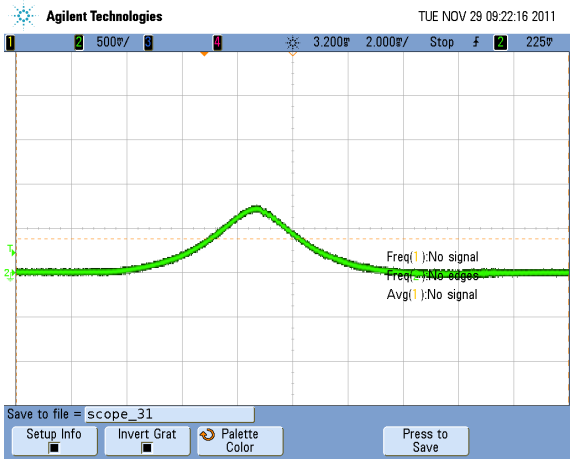


Figure 14: Drop Height: 15.5 cm
Damper Thickness: 6 mm
Peak Acceleration: 77 g
Pulse Duration: 9.5 ms

11.4 Appendix D (Team Budget)

Item Description	Item #	QTY	Unit Cost	Fees	Shipping	Total	Avail Budget
							7000
Back-up Funds	N/A	N/A	N/A	N/A	N/A	1000	6000
Accelerometer-3 axis	356A24	1	1034.1	0	55	1089.1	4910.9
Data Acquisition - DAC		1	700	0	35	735	4175.9
Linear Motor		1	1750	0	50	1800	2375.9
Linear Bearings (1/2)	8974T1	2	17.84	0	10	45.68	2330.22
Linear Bushings (1/2)	9533T3	2	14.38	0	10	38.76	2291.46
Linear Bearings (5/8)		2	21	0	10	52	2239.46
1/2" Drill Rod	8890K1	1	8.69	0	10	18.69	2220.77
5/8" Polished Rod		1	50	0	15	65	2155.77
Linear Encoder 1	AS5306a	2	5.31	0	5	15.62	2140.15
Linear Encoder 2	AS5306b	2	5.31	0	0	10.62	2129.53
Encoder strip	AS5000	4	6	0	0	24	2105.53
Aluminum Stock		1	200	0	0	200	1905.53
Steel Stock		1	200	0	0	200	1705.53
Signal Conditioning		1	400	0	10	410	1295.53
Viscoelastic Materiasl		1	500	0	50	550	745.53
Misc Hardware/ Safety		1	700	0	0	700	45.5299999999997
BUDGET REMAINING							45.5299999999997

11.5 Appendix E (Report on Statistical Analysis)

Shock Pulses and the Effects Contributed by Viscoelastic Damping Materials

Submitted to:
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December 13, 2011

Shock pulses and the effects contributed by viscoelastic damping materials
(December 2011)

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Abstract: Senior design team, Sandia M.A.S.T. (Miniature Accelerations Shock Tester) has been tasked with designing a shock testing apparatus for Dr. Scott Whalen of Sandia National Labs. Shock occurs when two objects collide, causing rapid deceleration for minute periods of time. It is this impulse that Dr. Whalen wishes to measure so that he may test his proprietary electronics under specific conditions of 1 to 10 milliseconds, and up to 200 g's. In order to accomplish this task, an understanding of how to replicate these conditions with accuracy and precision, as well as how to modify them according to his user inputs is to be gained. Current published information lacks uniformity and reliability, leaving the team with nothing better than educated guesses. This paper publishes findings from an experiment testing how the thickness and properties of certain materials affect shock pulse duration and magnitude, how height affects shock pulse duration and magnitude, and which factor is more significant. Statistical analyses of Factorial Regressions were performed determining that of the two selected for observation, the thickness of the viscoelastic material used is the most important factor with a statistical confidence of 99%.

Key Words: shock, viscoelastic, drop height, factor, factorial regression, accelerometer

I. INTRODUCTION

THIS document describes the work done by members of Sandia M.A.S.T. for their senior capstone project. Shock testers are used in industry to subject components or entire structures to shock over a regulated period of time. They range in form, function, cost, methods of actuation, and applicable standards to which they apply. There are multiple methods of accomplishing shock tests in the industry including pyrotechnics, hammer, and classical shock testing [1]. For the scope of this project, a classical shock testing apparatus is to be built and implemented according to Dr. Whalen of Sandia National Labs. This implies a vertical drop table with a means of actuation and a vertical post construction.

The information gained from this experiment will supplement the current senior design team with informed data, allowing the delivery of a precision instrument to Dr. Whalen. Being that this is the first time that this project has been instituted, this information will be forwarded onward to next year's design team who will repeat or carry onward with this design task, building from what we accomplish this year. The ability to have the information that we discover will save next year's team countless hours and reserve funds for proper allocation, new developments on the project.

A basic understanding of physical phenomena is crucial to designing the shock tower to the specifications provided. Dr. Whalen will have other applications that he does not yet know of or that he does not currently realize. If the solution delivered to him exceeds expectations, he will no doubt find it significantly more useful than originally anticipated, making the return on investments into these efforts worthwhile. It is the desire of my team to deliver a product to Sandia National Labs that exceeds these expectations allowing Dr. Whalen the continued use of our product.

Additionally, the outcome of this design will undoubtedly influence the net worth of the degrees of each team member,

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playing a direct role in our ability to be hired in the industry or to move on to graduate school. The aim of a senior design project is to be a showcase of the talents of each team member as an engineer. Producing a product compliant to published industry standards that exceeds the expectations of my sponsor would have a great impact on my overall livelihood as well as that of the rest of my team mates and teams to come in the future.

II. METHODS

1. Data Analysis and Test Constraints

To analyze the data, a factorial regression using Microsoft Excel is to be performed. A Factorial analysis is a common method of analyzing the importance and interaction of different factors of experimental data. This allows testing of a hypothesis when there are two or more independent variables. Drop height and the thickness of the viscoelastic material were the two independent variables in this experiment, compared to the dependent variables of the shock amplitude and the pulse duration. By compiling and analyzing data using a factorial ANOVA table, comparisons the two were made allowing the discovery of which is more important to the dependent variables.

This analysis will tell the team which factor, if any, is significant to both the magnitude of the pulse and the duration for which the pulse lasts. I will also be able to determine which material to use for a damping platform on the senior design project that will provide the optimum results with high accuracy and minimal resonance. Should the analysis prove that no factor is statistically significant, this will show that there is another physical phenomenon that needs explanation. The more likely outcome is that one factor will emerge as the most significant. This will drive the design choices, and resources of my design team, Sandia M.A.S.T.

An accelerometer purchased from PCB Piezotronics is the sensing element utilized for this project. The sensitivity is advertised online 10 mV/g with an accuracy of $\pm$15 percent. Our specific unit has sensitivity calibrations of 10.36 mv/g, 10.31 mv/g, and 10.29 mv/g for the x, y, and z axes respectively.

In order to derive useful data to the rest of the University and to be able to apply it in industry, tests adhere to current standards for performing shock tests. Available at the team's disposal are military specifications to guide the experiment. MIL-S-901D(NAVY) describes shock test procedures [2], and MIL-STD-810F describes test conditions such as temperature, humidity, and most importantly the accuracy to which shocks from acceleration are to be measured [3].

2. Test Apparatus

Figure 1 shows the conceptual design for the purposes of the designed experiment. Component (a) refers to the top and bottom portion of the apparatus. Constructed of inexpensive aluminum, its function is to provide a solid base that is level and will restrict the level of permissible resonance. Component (b) shows precision guide rails. These will be costly with respect to the structural components because they will be machined to tight tolerances to avoid interference with components (d). Components (c) and (h) display the sensors associated with the system. (c) shows the accelerometer, the most costly component with which I will collect the primary data samples. (h) is a conceptual component, a magnetic linear encoder which provides exact calibrated position and velocity. Included with (h) is a sensing magnet also shown in green. I will use this data alongside a mathematic model to compare theoretical and experimental values. Component (d) is the energy reduction system, bushings, which will allow smooth and repeatable drops. Resonance is unacceptable and will be limited. For these purposes I have chosen brass as a suitable material from which to construct component (e), or the drop table. (f) denotes the polymer sample, which is atop component (g), a mounting platform.

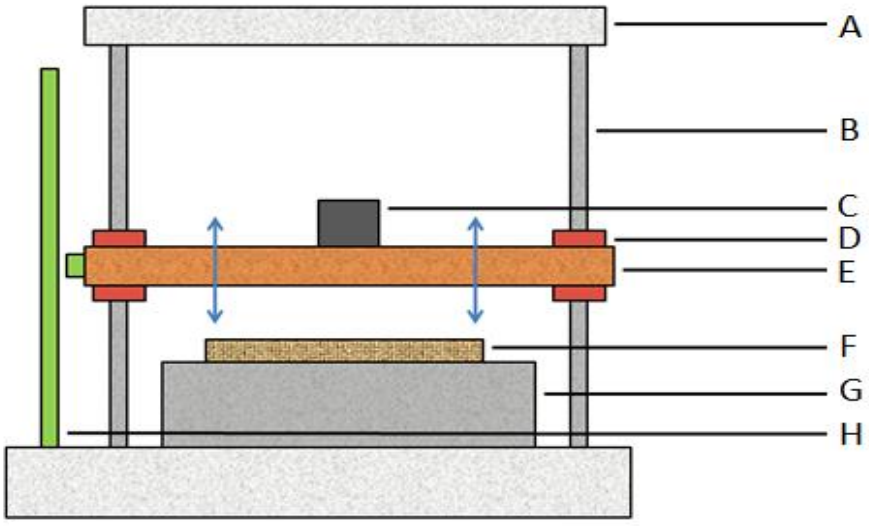

Figure 1 - Prototype used for testing

III. Experimental Design

1. Capstone math models

A primary objective of this project is to verify the mathematical models for the capstone project. This model demonstrates the necessary drop height for a gravity-actuated system, as well as what damping coefficient would be best for our design targets. Equation (1) is the model used to describe the acceleration of the impact with respect to time.

$$y_3 = -g - y_1 * \frac{k_b}{m} - y_2 * \frac{c_b}{m} \quad (1)$$

A list of the relevant variables for this equation is listed in Table 1 below.

Symbol	Units	Description
m	kg	Mass of Drop Table
y_1	m	Displacement
y_2	m/s	Velocity
y_3	m/s^2	Acceleration of Table
g	m/s^2	Acceleration of Gravity
k_b	N/m	Spring Stiffness
c_b	kg-s/m	Damping Coefficient

Table 1 - List of relevant variables

Figure 2 shows the output of this model, y_3, when run with values for the independent variables of (1). Appendix A contains the full code used to generate this plot.

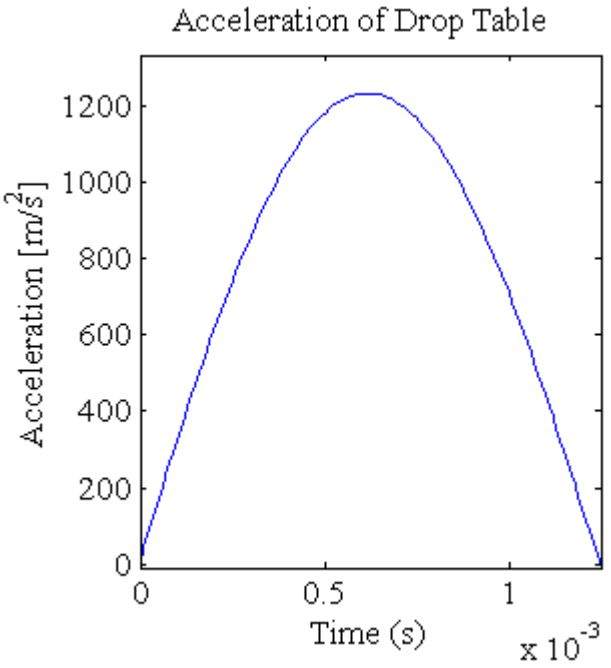

Figure 2 - Mathematical model for shock response

2. Statistical Models

For the statistical analysis, two factors were analyzed. The first factor was drop height. This factor is directly proportional to the amount of acceleration an object experiences during free fall motion. It is important to note that this acceleration is different from the pulse experienced during impact; however it is still vital for this experiment as it shows what input force is necessary to achieve the impact. The second variable examined was the thickness of the damping material used. Both independent variables, they were measured with respect to the dependent variables, pulse magnitude and pulse duration.

Foam was the damping material chosen for this experiment. Specifically ESD (Electro-Static Dissipating) foam, it was readily accessible and abundant in quantity. Its damping materials were deemed sufficient enough for prototyping and testing procedures. Young's modulus for such foams is determined to be within a range of 0.08 to 0.93 MPa [4]. This means that it is a fairly soft material in comparison with Steel of 210 Gpa [5], and justified the decision to use it as a material with which to modify the pulse. The values of this independent variable ranged from 3 mm thick for one pad to 6 mm thick for two pads. This variable was determined at a confidence of 95%

Drop height was chosen experimentally. Tests were performed to conform to the design targets. Thus, at a maximum of two pads of foam, a maximum drop height was determined to be 15.5 cm since the resulting maximum g's experienced by the accelerometer was 250 in amplitude. With 15.5 cm as the maximum value for this variable, the minimum value was set arbitrarily as 8.5 cm. This resulted in a minimum of around 50 g's, suitable for the given range of experimental accelerations. This variable was determined at a confidence of 95%.

Table 3 below summarizes the independent variables:

Drop Height (Factor A)		**Viscoelastic Thickness (Factor B)**	
Low (-)	*8.5[cm]*	1 Piece (-)	*3[mm]*
High (+)	*15.5[cm]*	1 Piece (-)	*3[mm]*
Low (-)	*8.5[cm]*	2 Pieces (+)	*6[mm]*
High (+)	*15.5[cm]*	2 Pieces (+)	*6[mm]*

Table 2 - Dependent variables and the applied ranges

IV. Experimental Procedure

1. Equipment used

Below is a list of equipment utilized during the experiment:

- Digital Multi-meter
- Oscilloscope
- Accelerometer
- Foam-pads (1” by 1”)
- Mounting platform for foam
- Drop test device
- Measuring tape
- Mounting wax

2. Setup

The experimental setup was fairly basic and had only a few steps. First, the drop test device was secured such that it would not move to maintain test consistency. Next, the measuring tape was secured next to the drop tester and secured. The accelerometer was affixed with the mounting wax and connected to the oscilloscope. The settings on the oscilloscope were set at 1.00 volts per vertical division, and 2 milliseconds per time division.

3. Procedure

The table of the drop tester was raised to a height of 8.5 cm from the initial position atop one pad of foam. With the oscilloscope ready to capture data, the table was released and a pulse was recorded. This was repeated 10 times, replacing the foam for every iteration. This process was imitated at 15.5 cm with one pad of foam, 8.5 cm and two pads of foam, and finally at 15.5 cm and two pads. 40 unique data points were collected. Each data point collected further data on the two dependent variables, and thus 80 data points in all were effectively gathered.

APPENDIX A

MATLAB CODE USED TO MODEL THE RESPONSE TO ACCELERATION PULSES

```
% Drop Table Simulation

clear all
close all
%
%% Assumptions:
% - Structure of Drop table and supporting mechanisms is assumed to be rigid.
%   > No energy is lost structures, perfectly elastic collision.
%   > Deformation in stopping object does not exceed material yield poing
%   > No deformation occurs in colliding body.
%
%% Parameters
%
m=2.0                                                    % Mass of drop table [kg]
d=0.08                                                   % Diamter of base [m]
L=0.04                                                   % Length of base [m]
A=pi/4*d^2                                               % Cross Sectional Area [m^2]
E=0.1e9                                                  % Young's Modulus of Rubber
[Pa]
%
g=9.81                                                   % Acceleration of Gravity
[m/s^2]
k_b=A*E/L                                                % Spring stiffness [N/m]
c_b=100                                                 % Damping Coefficient [kg-s/m]
%
param.m=m
param.k_b=k_b
param.c_b=c_b
param.g=g
%
%% Time Array
%
N=10000
tend=0.1                                                 % End simulation at t=0.01
seconds
t=linspace(0,tend,N)
dt=t(2)-t(1)
%
xo(1)=0                                                  % Initial Position [m]
xo(2)=-0.5                                                 % Initial Velocity [m/s]
%
%% ODE 45 Simulation
%
[t,x]=ode45(@(t,xo) impact(t,xo,param),t,xo);            % Call ODE45
%
%% Outputs
%
y1=x(:,1)                                                % Displacement [m]
y2=x(:,2)                                                % Velocity [m/s]

for i=1:length(y1)                                       % Acceleration is equal to
gravity before impact
    if y1(i)<0
        y3(i)=-g-y1(i)*k_b/m-y2(i)*c_b/m;
    else
        y3(i)=-g;
    end
end
%
```

```
%% Plots
%
subplot(3,1,1)
plot(t,y1)
title('Displacement of Drop Table')
axis([0 0.01 min(y1) max(y1)])
legend('x1')
ylabel('Displacement [m]')
%
subplot(3,1,2)
plot(t,y2)
title('Velocity of Drop Table')
axis([0 0.01 min(y2) max(y2)])
ylabel('Velocity [m/s]')
%
subplot(3,1,3)
plot(t,y3)
title('Accleration of Drop Table')
ylabel('Acceleration [m/s^2]')
xlabel('Time (s)')
axis([0 0.01 min(y3) max(y3)])

maxacc=max(y3)                                          % Maximum Acceleration of drop
table
```

REFERENCES

[1]

[2] "MIL-S-901 Rev. D," http://www.everyspec.com/MIL SPECS/MIL+SPECS+(MIL-S)/MIL-S-901D_14581/

[3] H. Egbert, "MIL-STD-810F," 2000, http://www.dtc.army.mil/navigator/

[4] http://www.biomedcentral.com/1471-2474/9/137

[5] Gere, James. Mechanics of Materials. 8. 2009. 26. Print.

[6]

11.6 Appendix G (Damping Materials)

PMC®-746

Polyurethane Rubber Compound

www.smooth-on.com

PRODUCT OVERVIEW

PMC®-746 was developed to make molds for casting gypsum plasters. Like PMC®-744, this product is well suited for use as a rubber case mold – especially large case molds where extra rigidity is required. Shore hardness is 60A. Because of its durability and moisture resistant properties PMC®-746 is also used by zoos and museums for a variety of mold-making, display and exhibit applications. It features a convenient mix ratio (2:1 by weight or volume), and contains no mercury.

Other applications include making plaster block molds, reproducing ornamental plaster (architectural restoration), pre-cast concrete molds, casting waxes, Smooth-On rigid polyurethanes and epoxies and also for making a variety of special effects for movies and theatre.

PROCESSING RECOMMENDATIONS

START BY PREPARING YOUR MODEL...

Preparation - Materials should be stored and used in a warm environment (73°F/23°C). They also have a limited shelf life and should be used as soon as possible. Wear safety glasses, long sleeves and rubber gloves to minimize contamination risk.

Some Materials Must Be Sealed - To prevent adhesion between the rubber and model surface, models made of porous materials (gypsum plasters, concrete, wood, stone, etc.) must be sealed prior to applying a release agent. SuperSeal® or One Step® (available from Smooth-On) are fast drying sealers suitable for sealing porous surfaces without interfering with surface detail. A high quality spray shellac is suitable for sealing modeling clays that contain sulfur or moisture (water based). Thermoplastics (polystyrene) must also be sealed with shellac or PVA.

TECHNICAL OVERVIEW

Mix Ratio: 2A : 1B by weight or volume	
Mixed Viscosity (cps): 1,200	(ASTM D-2393)
Specific Gravity (g/cc): 1.03	(ASTM D-1475)
Specific Volume (cu. in. /lb.): 26.9	
Pot Life: 15 minutes (73°F/23°C)	(ASTM D-2471)
Cure time: 16 hours (73°F/23°C)	
Color: Amber (color may vary from batch to batch)	
Shore A Hardness: 60	(ASTM D-2240)
Tensile Strength (psi): 700	(ASTM D-412*)
100% Modulus (psi)**:** 220	(ASTM D-412*)
Elongation @ Break: 650%	(ASTM D-412*)
Die C Tear Strength (pli)**:** 100	(ASTM D-624*)
Shrinkage: < .001 in./in.	(ASTM D-2566*)

* Value measured after 7 days at 73°F/23°

In all cases, the sealing agent should be applied and allowed to completely dry prior to applying a release agent.

Non-Porous Surfaces - Metal, glass, hard plastics, sulfur free clays, etc. require only a release agent.

Applying A Release Agent - A release agent is necessary to facilitate demolding when casting into or over most surfaces. Use a release agent made specifically for mold making (Universal® Mold Release available from Smooth-On). A liberal coat of release agent should be applied onto all surfaces that will contact the rubber.

IMPORTANT: To ensure thorough coverage, lightly brush the release agent with a soft brush over all surfaces of the model. Follow with a light mist coating and let the release agent dry for 30 minutes.

Because no two applications are quite the same, a small test application to determine suitability for your project is recommended if performance of this material is in question.

MEASURING & MIXING...

Liquid urethanes are **moisture sensitive** and will absorb atmospheric moisture. Mixing tools and containers should be clean and made of metal, glass or plastic. Materials should be stored and used in a warm environment (73°F/23°C).

IMPORTANT: Shelf life of product is drastically reduced after opening. Immediately replacing the lids on both containers after dispensing product will prolong the shelf life of the unused product. **XTEND-IT® Dry Gas Blanket** (available from Smooth-On) will significantly prolong the shelf life of unused liquid urethane products.

IMPORTANT: Shelf life of product is reduced after opening. Remaining product should be used as soon as possible. Immediately replacing the lids on both containers after dispensing product will help prolong the shelf life of the unused product. **XTEND-IT® Dry Gas Blanket** (available from Smooth-On) will significantly prolong the shelf life of unused liquid urethane products.

Safety First!

The Material Safety Data Sheet (MSDS) for this or any Smooth-On product should be read prior to use and is available upon request from Smooth-On. All Smooth-On products are safe to use if directions are read and followed carefully.

Be careful

Part A is a TDI prepolymer. Vapors, which can be significant if material is heated or sprayed, cause lung damage and sensitization. Use only with adequate ventilation. Contact with skin and eyes may cause severe irritation. Flush eyes with water for 15 minutes and seek immediate medical attention. Remove from skin with waterless hand cleaner followed by soap and water Prepolymers contain trace amounts of TDI which, if ingested, must be considered a potential carcinogen. Refer to MSDS .

Part B is irritating to the eyes and skin. If contaminated, flush eyes with water for 15 minutes and seek immediate medical attention. Remove from skin with soap and water. When mixing with Part A follow precautions for handling isocyanates.

Important: The information contained in this bulletin is considered accurate. However, no warranty is expressed or implied regarding the accuracy of the data, the results to be obtained from the use thereof, or that any such use will not infringe upon a patent. User shall determine the suitability of the product for the intended application and assume all risk and liability whatsoever in connection therewith.

IMPORTANT: Pre Mix the Part B before using. After dispensing two Parts A and one Part B into mixing container, mix thoroughly for at least 3 minutes making sure that you scrape the sides and bottom of the mixing container several times.

If Mixing Large Quantities (16 lbs./7 kgs. or more) at one time, use a mechanical mixer (i.e. Squirrel Mixer or equal) for 3 minutes followed by careful hand mixing for one minute as directed above. Then, pour entire quantity into a new, clean mixing container and do it all over again. Although this product is formulated to minimize air bubbles in your the cured rubber, vacuum degassing will further reduce entrapped air. A pressure casting technique using a pressure chamber can yield totally bubble free molds. Contact Smooth-On or your distributor for further information about vacuum degassing or pressure casting.

POURING, CURING & PERFORMANCE...

Pouring - For best results, pour your mixture in a single spot at the lowest point of the containment field. Let the rubber seek its level up and over the model. **A uniform flow will help minimize entrapped air.** The liquid rubber should level off at least 1/2" (1.3 cm) over the highest point of the model surface

Curing - Allow rubber to cure overnight (at least 16 hours) at room temperature (73°F/23°C) before demolding. Cure time can be reduced with mild heat or by adding Smooth-On "Kick-It®" Cure Accelerator. Do not cure rubber where temperature is less than 65°F/18°C.

Post Curing - After rubber has cured at room temperature, heating the rubber to 150°F (65°C) for 4 to 8 hours will increase physical properties and performance.

Using The Mold - If using as a mold material, a release agent should be applied to the mold before each casting. The type of release agent to use depends on the material being cast. The proper release agent for **wax, liquid rubber or thermosetting materials** (i.e. Smooth-On liquid plastics) is a spray release made specifically for mold making (available from Smooth-On or your distributor). Prior to casting **gypsum plaster materials,** sponge the mold with a soap solution for better plaster flow and easy release. **In & Out® II Water Based Release Concentrate** (available from Smooth-On) is recommended for releasing abrasive materials like **concrete**.

Performance & Storage - Fully cured rubber is tough, durable and will perform if properly used and stored. The physical life of the rubber depends on how you use it.

SMOOTH-ON SINCE 1895

Call Us Anytime With Questions About Your Application.

Toll-free: **(800) 762-0744** Fax: **(610) 252-6200**

The new **www.smooth-on.com** is loaded with information about mold making, casting and more.

PMC®-780 Dry & PMC®-780 Wet

Industrial Liquid Rubber Compounds

www.smooth-on.com

PRODUCT OVERVIEW

PMC-780 is a premium performance urethane rubber that offers exceptional strength, durability and abrasion resistance. **PMC-780 *DOES NOT* CONTAIN MOCA** – a known cancer causing agent and hazard. Mixed two parts A to one part B by weight, PMC-780 pours easily and cures at room temperature with negligible shrinkage to a solid Shore 80A rubber.

Pick The One Best Suited For Your Application: Original **PMC-780 Dry does not exude oil.** New **PMC-780 Wet contains a built-in release agent** to aid in demolding concrete. (Note: "wet" rubber has a higher net shrinkage value over time vs. "dry " rubber.)

Both are used around the world for casting abrasive materials such as concrete (pre-cast concrete, making concrete stamping pads, etc.) and gypsum plasters with high exotherms. PMC-780 Dry is also commonly used to make rubber mechanical parts of varying configurations (gaskets, wheels, and pullies) as well as ball mill liners and vibration/shock pads.

PROCESSING RECOMMENDATIONS

START BY PREPARING YOUR MODEL...

Preparation - These products have a limited shelf life and should be used as soon as possible. Materials should be stored and used at room temperature (73°F/23°C). Humidity should be low. Wear safety glasses, long sleeves and rubber gloves to minimize contamination risk. Good ventilation (room size) is necessary.

Some Materials Must Be Sealed - To prevent adhesion between the rubber and model surface, models made of porous materials (gypsum plasters, concrete, wood, stone, etc.) must be sealed prior to applying a release agent. SuperSeal® or One Step® (available from Smooth-On) is a fast drying sealer suitable for sealing porous surfaces without interfering with surface detail. You can also use Sonite® Wax. A high quality Shellac is suitable for sealing modeling clays that contain sulfur or moisture (water based).

TECHNICAL OVERVIEW

Mix Ratio: 2A : 1B by weight or volume	
Mixed Viscosity (cps): 2,000	(ASTM D-2393)
Specific Gravity (g/cc): 1.02	(ASTM D-1475)
Specific Volume (cu. in. /lb.): 27.2	
Pot Life: 25 minutes (73°F/23°C)	(ASTM D-2471)
Cure time: 48 hrs (73°F/23°C)	
Color: Light Amber	
Shore A Hardness: 80	(ASTM D-2240)
Tensile Strength (psi): 900	(ASTM D-412)
100% Modulus (psi)**:** 400	(ASTM D-412)
Elongation @ Break: 700%	(ASTM D-412)
Die C Tear Strength (pli)**:** 200	(ASTM D-624)
Shrinkage: < .001 in./in.	(ASTM D-2566)

* All values measured after 7 days at 73°F/23°C

In all cases, the sealing agent should be applied and allowed to completely dry prior to applying a release agent.

Non-Porous Surfaces - Metal, glass, hard plastics, sulfur free clays, etc. require only a release agent.

Applying A Release Agent - A release agent is necessary to facilitate demolding when casting into or over most surfaces. Use a release agent made specifically for mold making (Universal® Mold Release available from Smooth-On). A liberal coat of release agent should be applied onto all surfaces that will contact the rubber.

IMPORTANT: To ensure thorough coverage, lightly brush the release agent with a soft brush over all surfaces of the model. Follow with a light mist coating and let the release agent dry for 30 minutes.

Because no two applications are quite the same, a small test application to determine suitability for your project is recommended if performance of this material is in question.

MEASURING & MIXING...

Liquid urethanes are **moisture sensitive** and will absorb atmospheric moisture. Mixing tools and containers should be clean and made of metal or plastic.

IMPORTANT: Shelf life of product is drastically reduced after opening. Immediately replacing the lids on containers after dispensing product will prolong the shelf life of the unused product. **XTEND-IT® Dry Gas Blanket** (available from Smooth-On) will significantly prolong the shelf life of unused liquid urethane products.

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Safety First!

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Be careful

Part A is a TDI prepolymer. Vapors, which can be significant if prepolymer is heated or sprayed, may cause lung damage and sensitization. Use only with adequate ventilation. Contact with skin and eyes may cause severe irritation. Flush eyes with water for 15 minutes and seek immediate medical attention. Remove from skin with soap and water. Prepolymers contain trace amounts of TDI which, if ingested, must be considered a potential carcinogen. Refer to the MSDS for this product. Avoid skin contact by wearing long sleeve garments and latex gloves. If skin contact is made, remove immediately with soap and water. If eye contact is made, flush eyes with water for 15 minutes and seek immediate medical attention.

Important: The information contained in this bulletin is considered accurate. However, no warranty is expressed or implied regarding the accuracy of the data, the results to be obtained from the use thereof, or that any such use will not infringe a patent. User shall determine the suitability of the product for its intended applications and assumes all risk and liability whatsoever in connection therewith.

IMPORTANT: Pre Mix the Part B before using. After dispensing the required amounts of Parts A and B into mixing container, mix thoroughly for at least 3 minutes making sure that you scrape the sides and bottom of the mixing container several times.

If Mixing Large Quantities (24 lbs./11 kgs. or more) at one time, we suggest using a mechanical mixer (i.e. Squirrel Mixer or equal) for 3 minutes followed by careful hand mixing for one minute as directed above. Then, pour entire quantity into a new, clean mixing container and do it all over again.

Although this product is formulated to minimize air bubbles in the cured rubber, vacuum degassing will further reduce entrapped air. A pressure casting technique using a pressure chamber can yield totally bubble free castings. Contact Smooth-On or your distributor for further information about vacuum degassing or pressure casting.

POURING, CURING & PERFORMANCE...

Pouring - For best results, pour your mixture in a single spot at the lowest point of the containment field. Let the rubber seek its level up and over the model. **A uniform flow will help minimize entrapped air.** The liquid rubber should level off at least 1/2" (1.3 cm) over the highest point of the model surface.

Curing - Allow the mold to cure (at least 48 hours) at room temperature (73°F/23°C) before demolding. Do not cure rubber in temperatures less than 65°F/18°C. Cure time can be reduced with mild heat or by adding Smooth-On "Kick-It®" Cure Accelerator.

Post Curing - After rubber has cured at room temperature, heating the rubber to 150°F (65°C) for 4 to 8 hours will increase physical properties and performance.

Using The Mold - If using as a mold material, a release agent should be applied to the mold before each casting. The type of release agent to use depends on the material being cast. The proper release agent for **wax, liquid rubber or thermosetting materials** (i.e. Smooth-On liquid plastics) is a spray release made specifically for mold making (available from Smooth-On or your distributor). Prior to casting **gypsum plaster materials,** sponge the mold with a soap solution for better plaster flow and easy release. **In & Out® II Water Based Release Concentrate** (available from Smooth-On) is recommended for releasing abrasive materials like **concrete**.

Performance & Storage - Fully cured rubber is tough, durable and will perform if properly used and stored. The physical life of the rubber depends on how you use it. Contact Smooth-On directly with questions about this material relative to your application.

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PMC®-770

Industrial Liquid Rubber Compound

www.smooth-on.com

PRODUCT OVERVIEW

PMC®-770 is a Shore 70A addition to our line of industrial liquid rubber products (such as PMC®-780 and PMC®-790) used for a variety industrial and casting applications. Mixed two parts A to one part B by weight, PMC®-770 pours easily and cures at room temperature to a solid Shore 70A rubber that has exceptional performance characteristics and dimensional stability.

It is suitable for production casting of abrasive materials such as concrete (pre-cast concrete, making concrete stamping pads, etc.) and gypsum plasters with high exotherms. It is also suitable for rubber mechanical parts of varying configurations (gaskets, wheels, pullies) as well as ball mill liners and vibration/shock pads.

PROCESSING RECOMMENDATIONS

START BY PREPARING YOUR MODEL...

Preparation - These products have a limited shelf life and should be used as soon as possible. Materials should be stored and used at room temperature (73°F/23°C). Humidity should be low. Wear safety glasses, long sleeves and rubber gloves to minimize contamination risk. Good ventilation (room size) is necessary.

Some Materials Must Be Sealed - To prevent adhesion between the rubber and model surface, models made of porous materials (gypsum plasters, concrete, wood, stone, etc.) must be sealed prior to applying a release agent. SuperSeal® or One Step® (available from Smooth-On) is a fast drying sealer suitable for sealing porous surfaces without interfering with surface detail. You can also use Sonite® Wax. A high quality Shellac is suitable for sealing modeling clays that contain sulfur or moisture (water based).

TECHNICAL OVERVIEW

Mix Ratio: 2A : 1B by weight	
Mixed Viscosity (cps): 3,000	(ASTM D-2393)
Specific Gravity (g/cc): 1.04	(ASTM D-1475)
Specific Volume (cu. in. /lb.): 26.5	
Pot Life: 30 minutes (73°F/23°C)	(ASTM D-2471)
Cure time: 16 hrs (73°F/23°C)	
Color: Light Amber	
Shore A Hardness: 70	(ASTM D-2240)
Tensile Strength (psi): 750	(ASTM D-412)
100% Modulus (psi)**:** 250	(ASTM D-412)
Elongation @ Break: 750%	(ASTM D-412)
Die C Tear Strength (pli)**:** 200	(ASTM D-624)
Shrinkage: < .001 in./in.	(ASTM D-2566)

* All values measured after 7 days at 73°F/23°C

In all cases, the sealing agent should be applied and allowed to completely dry prior to applying a release agent.

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Part A is a TDI prepolymer. Vapors, which can be significant if prepolymer is heated or sprayed, may cause lung damage and sensitization. Use only with adequate ventilation. Contact with skin and eyes may cause severe irritation. Flush eyes with water for 15 minutes and seek immediate medical attention. Remove from skin with soap and water. Prepolymers contain trace amounts of TDI which, if ingested, must be considered a potential carcinogen. Refer to the MSDS for this product. Avoid skin contact by wearing long sleeve garments and latex gloves. If skin contact is made, remove immediately with soap and water. If eye contact is made, flush eyes with water for 15 minutes and seek immediate medical attention.

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POURING, CURING & PERFORMANCE...

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Curing - Allow the mold to cure (at least 16 hours) at room temperature (73°F/23°C) before demolding. Do not cure rubber in temperatures less than 65°F/18°C. Cure time can be reduced with mild heat or by adding Smooth-On "Kick-It®" Cure Accelerator.

Post Curing - After rubber has cured at room temperature, heating the rubber to 150°F (65°C) for 4 to 8 hours will increase physical properties and performance.

Using The Mold - If using as a mold material, a release agent should be applied to the mold before each casting. The type of release agent to use depends on the material being cast. The proper release agent for **wax, liquid rubber or thermosetting materials** (i.e. Smooth-On liquid plastics) is a spray release made specifically for mold making (available from Smooth-On or your distributor). Prior to casting **gypsum plaster materials,** sponge the mold with a soap solution for better plaster flow and easy release. **In & Out® II Water Based Release Concentrate** (available from Smooth-On) is recommended for releasing abrasive materials like **concrete**.

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SMOOTH-ON SINCE 1895

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11.7 Appendix H (Linear Encoder Spec Sheet)

1 General Description

The AS5304/AS5306 are single-chip IC's with integrated Hall elements for measuring linear or rotary motion using multi-pole magnetic strips or rings.

This allows the usage of the AS5304/AS5306 in applications where the Sensor IC cannot be mounted at the end of a rotating device (e.g. at hollow shafts). Instead, the AS5304/AS5306 are mounted off-axis underneath a multi-pole magnetized ring or strip and provides a quadrature incremental output with 40 pulses per pole period at speeds of up to 20 meters/sec (AS5304) or 12 meters/sec (AS5306).

A single index pulse is generated once for every pole pair at the Index output.

Using, for example, a 32pole-pair magnetic ring, the AS5304/AS5306 can provide a resolution of 1280 pulses/rev, which is equivalent to 5120 positions/rev or 12.3bit. The maximum speed at this configuration is 9375 rpm.

The pole pair length is 4mm (2mm north pole / 2mm south pole) for the AS5304, and 2.4mm (1.2mm north pole / 1.2mm south pole) for the AS5306. The chip accepts a magnetic field strength down to 5mT (peak).

Both chips are available with **push-pull outputs (AS530xA)** or with **open drain outputs (AS530xB)**.

The AS5304/AS5306 are available in a small 20-pin TSSOP package and specified for an operating ambient temperature of -40° to +125°C.

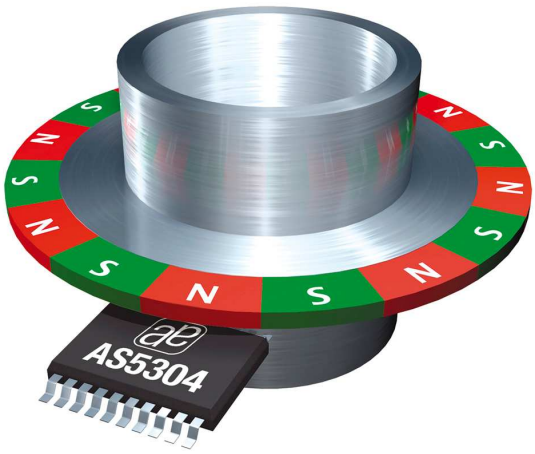


Figure 1: AS5304 (AS5306) with multi-pole ring magnet.

2 Benefits

- Complete system-on-chip
- High reliability due to non-contact sensing
- Suitable for the use in harsh environments
- Robust against external magnetic stray fields

3 Key Features

- High speed, up to 20m/s (AS5304)
  12m/s (AS5306)
- Magnetic pole pair length: **4mm (AS5304)** or
  2.4mm (AS5306)
- Resolution: **25µm (AS5304)** or **15µm (AS5306)**
- 40 pulses / 160 positions per magnetic period.
- 1 index pulse per pole pair
- Linear movement measurement using multi-pole magnetic strips
- Circular off-axis movement measurement using multi-pole magnetic rings
- 4.5 to 5.5V operating voltage
- Magnetic field strength indicator, magnetic field alarm for end-of-strip or missing magnet

4 Applications

The AS5304/AS5306 are ideal for high speed linear motion and off-axis rotation measurement in applications such as

- electrical motors
- X-Y-stages
- rotation knobs
- industrial drives

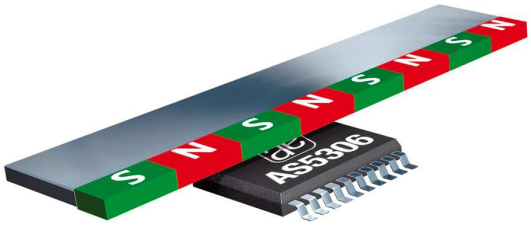


Figure 2: AS5306 (AS5304) with magnetic multi-pole strip magnet for linear motion measurement

5 Functional Description

The AS5304/AS5306 require a multi-pole magnetic strip or ring with a pole length of 2mm (4mm pole pair length) on the AS5304, and a pole length of 1.2mm (2.4mm pole pair length) on the AS5306. The magnetic field strength of the multi-pole magnet should be in the range of 5 to 60mT at the chip surface.

The Hall elements on the AS5304/AS5306 are arranged in a linear array.

By moving the multi-pole magnet over the Hall array, a sinusoidal signal (SIN) is generated internally. With proper configuration of the Hall elements, a second 90° phase shifted sinusoidal signal (COS) is obtained. Using an interpolation circuit, the length of a pole pair is divided into 160 positions and further decoded into 40 quadrature pulses.

An Automatic Gain Control provides a large dynamic input range of the magnetic field.

An Analog output pin (AO) provides an analog voltage that changes with the strength of the magnetic field (see chapter 8).

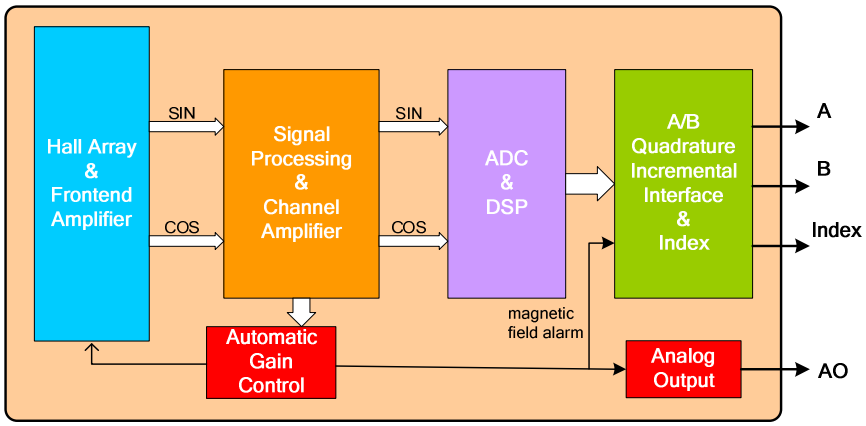


Figure 3: AS5304 / AS5306 block diagram

6 Sensor Placement in Package

TSSOP20 / 0.65mm pin pitch

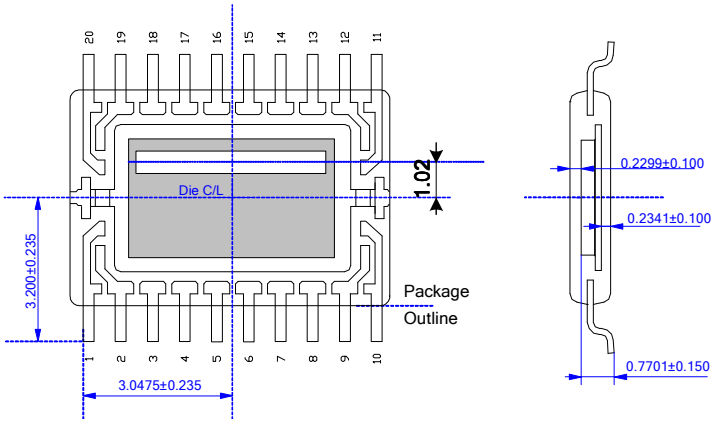


Figure 4: Sensor in package

Die Tilt Tolerance ±1°

6.1 Pin Description

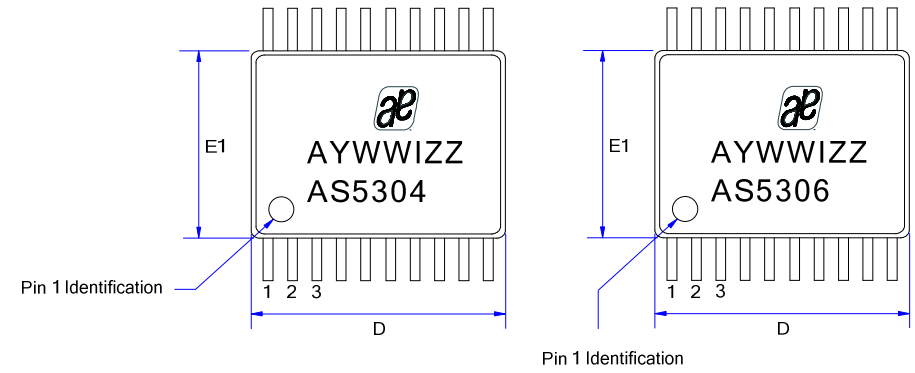
Pin	Pin Name	Pin Type	Notes
1	VSS	S	Supply ground
2	A	DO_OD	Incremental quadrature position output A. Short circuit current limitation
3	VDDP	S	Peripheral supply pin, connect to VDD
4	B	DO_OD	Incremental quadrature position output B. Short Circuit Current Limitation
5,12,13, 14,17,18,19	TEST	AIO	test pins, must be left open
6	AO	AO	AGC Analogue Output. (Used to detect low magnetic field strength)
7	VDD	S	Positive supply pin
8	Index	DO_OD	Index output, active HIGH. Short Circuit Current Limitation
9,10,11	TEST	AIO	test pins, must be left open
15	TEST_GND	S	test pin, must be connected to VSS
16	VDDA Hall	S	Hall Bias Supply Support (connected to VDD)
20	ZPZmskdis	DI	Test input, connect to VSS during operation

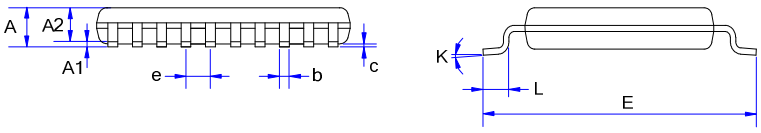
PIN Types:

S	supply pin	AO	analogue output
AIO	analog input / output	DI	digital input
DO_OD	digital output push pull or open drain (programmable)		

6.2 Package Drawings and Markings

20 Lead Thin Shrink Small Outline Package – **TSSOP20**





Dimensions						
Symbol	mm			inch		
	Min	Typ	Max	Min	Typ	Max
A	-	-	1.20	-	-	0.047
A1	0.05	-	0.15	0.002	-	0.006
A2	0.80	1.00	1.05	0.031	0.039	0.041
b	0.19	-	0.30	0.007	-	0.012
c	0.09	-	0.20	0.004	-	0.008
D	6.40	6.50	6.60	0.252	0.256	0.260
E		6.40			0.252	
E1	4.30	4.40	4.50	0.169	0.173	0.177
e		0.65			0.0256	
K	0°	-	8°	0°	-	8°
L	0.45	0.60	0.75	0.018	0.024	0.030

Marking: AYWWIZZ

A: Pb-Free Identifier
Y: Last Digit of Manufacturing Year
WW: Manufacturing Week
I: Plant Identifier
ZZ: Traceability Code

JEDEC Package Outline Standard:
MO-153-AC

Thermal Resistance $R_{th(j-a)}$:
89 K/W in still air, soldered on PCB.

IC's marked with a white dot or the letters "ES" denote Engineering Samples

6.3 Electrical Connection

The supply pins VDD, VDDP and VDDA are connected to +5V. Pins VSS and TEST_GND are connected to the supply ground. A 100nF decoupling capacitor close to the device is recommended.

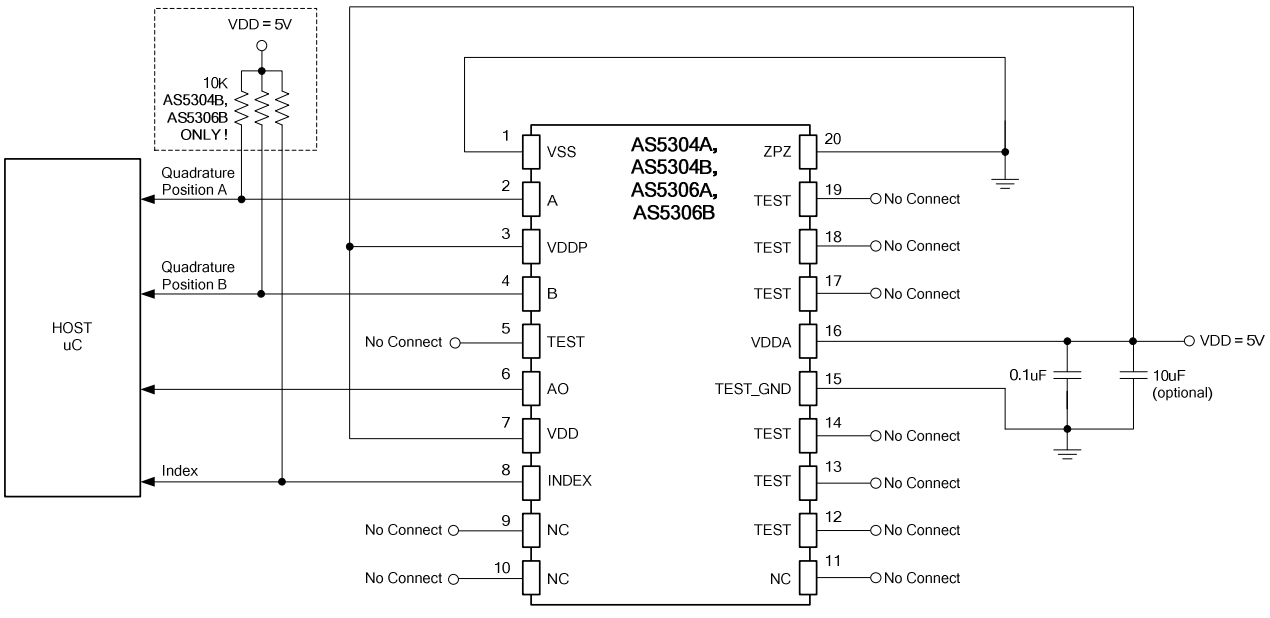


Figure 5: Electrical connection of the AS5304/AS5306

7 Incremental Quadrature AB Output

The digital output is compatible to optical incremental encoder outputs. Direction of rotation is encoded into two signals A and B that are phase-shifted by 90°. Depending on the direction of rotation, A leads B (CW) or B leads A (CCW).

7.1.1 Index Pulse

A single index pulse is generated once for every pole pair. One pole pair is interpolated to 40 quadrature pulses (160 steps), so one index pulse is generated after every 40 quadrature pulses (see Figure 6)

The Index output is switched to Index = high, when a magnet is placed over the Hall array as shown in Figure 7, top graph: the north pole of the magnet is placed over the left side of the IC (top view, pin#1 at bottom left) and the south pole is placed over the right side of the IC.

The index output will switch back to Index = low, when the magnet is moved by one LSB from position X=0 to X=X1, as shown in Figure 7, bottom graph. One LSB is 25µm for AS5304 and 15µm for AS5306.

Note: Since the small step size of 1 LSB is hardly recognizable in a correctly scaled graph it is shown as an exaggerated step in the bottom graph of Figure 7.

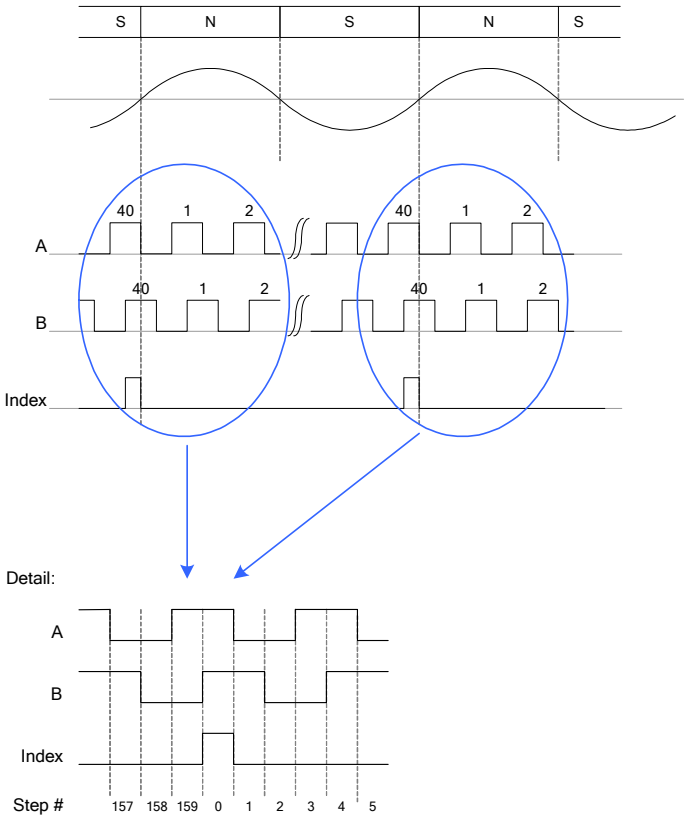


Figure 6: Quadrature A / B and Index output

7.1.2 Magnetic Field Warning Indicator

The AS5304 can also provide a low magnetic field warning to indicate a missing magnet or when the end of the magnetic strip has been reached. This condition is indicated by using a combination of A, B and Index, that does not occur in normal operation:

A low magnetic field is indicated with:

Index = high
A=B=low

7.1.3 Vertical Distance between Magnet and IC

The recommended vertical distance between magnet and IC depends on the strength of the magnet and the length of the magnetic pole.

Typically, the vertical distance between magnet and chip surface should not exceed ½ of the pole length.

That means for AS5304, having a pole length of 2.0mm, the maximum vertical gap should be 1.0mm,

For the AS5306, having a pole length of 1.2mm, the maximum vertical gap should be 0.6mm

These figures refer to the chip surface. Given a typical distance of 0.2mm between chip surface and IC package surface, the recommended vertical distances between **magnet and IC surface** are therefore:

AS 5304: ≤ 0.8mm

AS 5306: ≤ 0.4mm

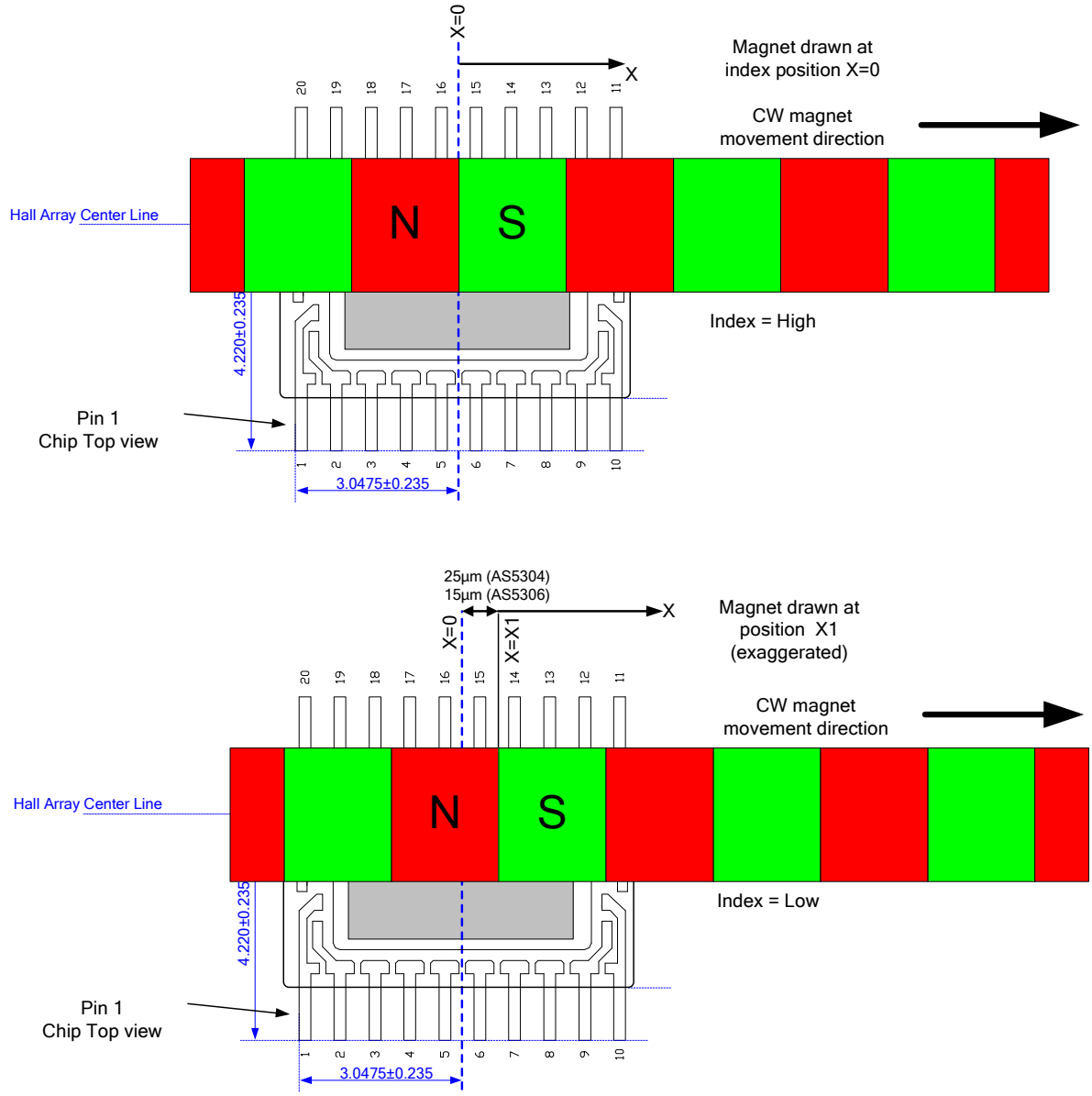


Figure 7: Magnet placement for index pulse generation

7.1.4 Soft Stop Feature for Linear Movement Measurement

When using long multi-pole strips, it may often be necessary to start from a defined home (or zero) position and obtain absolute position information by counting the steps from the defined home position. The AS5304/AS5306 provide a soft stop feature that eliminates the need for a separate electro-mechanical home position switch or an optical light barrier switch to indicate the home position.

The magnetic field warning indicator (see 7.1.2) together with the index pulse can be used to indicate a unique home position on a magnetic strip:

1. First the AS5304/AS5306 move to the end of the strip, until a magnetic field warning is displayed (Index = high, A=B=low)
2. Then, the AS5304/AS5306 move back towards the strip until the first index position is reached (note: an index position is generated once for every pole pair, it is indicated with: Index = high, A=B= high). Depending on the polarity of the strip magnet, the first index position may be generated when the end of the magnet strip only covers one half of the Hall array. This position is not recommended as a defined home position, as the accuracy of the AS5304/AS5306 are reduced as long as the multi-pole strip does not fully cover the Hall array.

3. It is therefore recommended to continue to the next (second) index position from the end of the strip (Index = high, A=B= high). This position can now be used as a defined home position.

7.2 Incremental Hysteresis

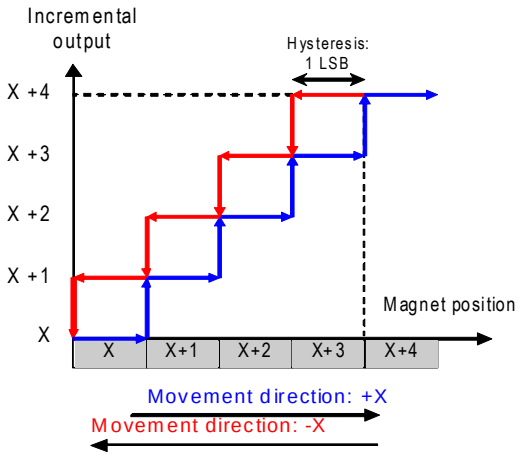


Figure 8: Hysteresis of the incremental output

If the magnet is sitting right at the transition point between two steps, the noise in the system may cause the incremental outputs to jitter back and forth between these two steps, especially when the magnetic field is weak.

To avoid this unwanted jitter, a hysteresis has been implemented. The hysteresis lies between 1 and 2 LSB, depending on device scattering. Figure 8 shows an example of 1LSB hysteresis: the horizontal axis is the lateral position of the magnet as it scans across the IC, the vertical axis is the change of the incremental outputs, as they step forward (blue line) with movement in +X direction and backward (red line) in –X direction.

Note: 1LSB = 25µm for AS5304, 15µm for AS5306

7.3 Integral Non-Linearity (INL)

The INL (integral non-linearity) is the deviation between indicated position and actual position. It is better than 1LSB for both AS5304 and AS5306, assuming an ideal magnet. Pole length variations and imperfections of the magnet material, which lead to a non-sinusoidal magnetic field will attribute to additional linearity errors.

7.3.1 Error Caused by Pole Length Variations

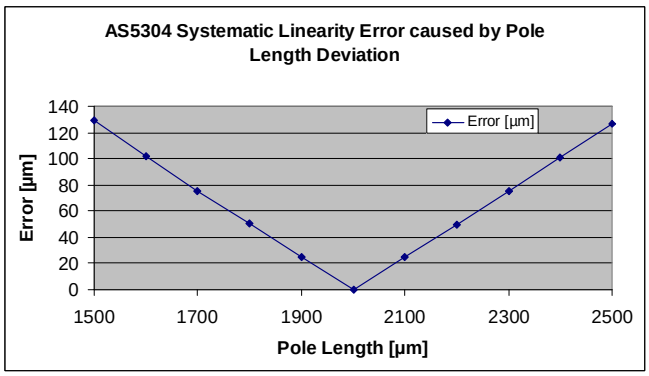


Figure 9: Additional error caused by pole length variation: AS5304

Figure 9 and Figure 10 show the error caused by a non-ideal pole length of the multi-pole strip or ring.

This is less of an issue with strip magnets, as they can be manufactured exactly to specification using the proper magnetization tooling.

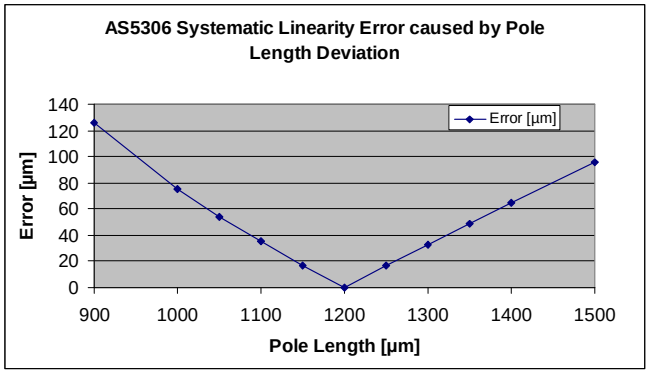


Figure 10: Additional error caused by pole length variation: AS5306

However, when using a ring magnet (see Figure 1) the pole length differs depending on the measurement radius. For optimum performance it is therefore essential to mount the IC such that the Hall sensors are exactly underneath the magnet at the radius where the pole length is 2.0mm (AS5304) or 1.2mm (AS5306), see also 8.1.2.

Note that this is an additional error, which must be added to the intrinsic errors INL (see 7.3) and DNL (see 7.4).

7.4 Dynamic Non-Linearity (DNL)

The DNL (dynamic non-linearity) describes the non-linearity of the incremental outputs from one step to the next. In an ideal system, every change of the incremental outputs would occur after exactly one LSB (e.g. 25µm on AS5304). In practice however, this step size is not ideal, the output state will change after 1LSB +/-DNL. The DNL must be <+/- ½ LSB to avoid a missing code. Consequently, the incremental outputs will change when the magnet movement over the IC is minimum 0.5 LSB and maximum 1.5 LSB's.

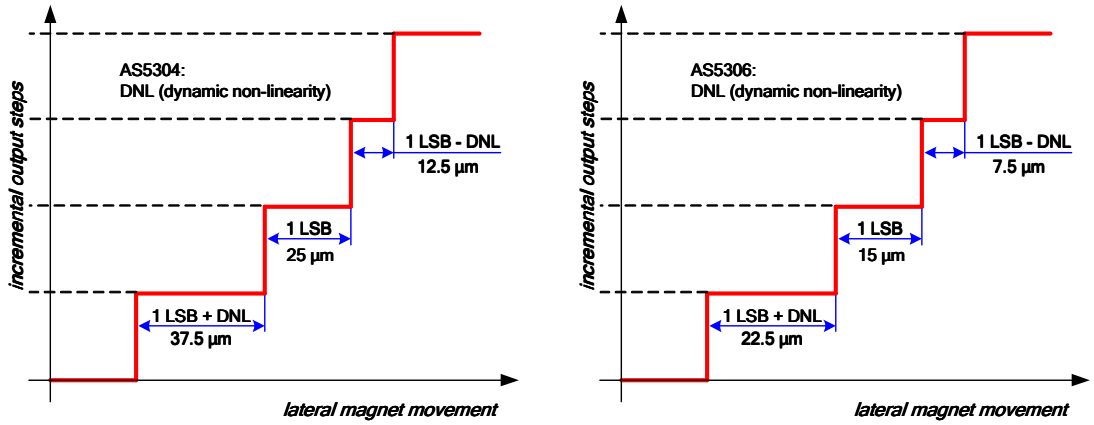


Figure 11: DNL of AS5304 (left) and AS5306 (right)

8 The AO Output

The Analog Output (AO) provides an analog output voltage that represents the Automatic Gain Control (AGC) of the Hall sensors signal control loop.

This voltage can be used to monitor the magnetic field strength and hence the gap between magnet and chip surface:

- Short distance between magnet and IC → strong magnetic field → low loop gain → low AO voltage
- Long distance between magnet and IC → weak magnetic field → high loop gain → high AO voltage

For ideal operation, the AO voltage should be between 1.0 and 4.0V (typical; see 9.5).

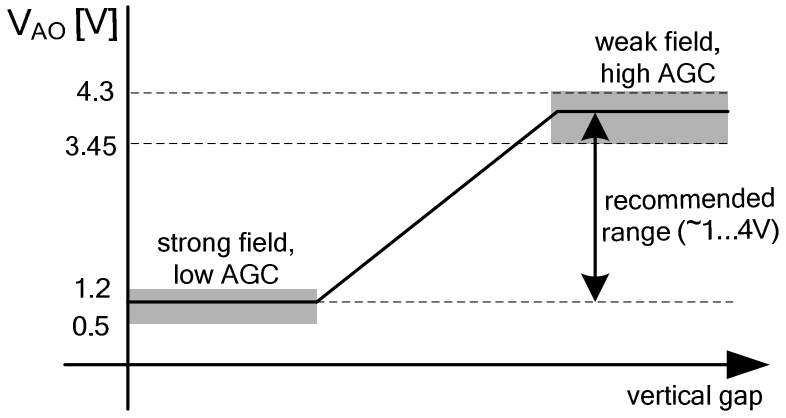


Figure 12: AO output versus AGC, magnetic field strength, magnet-to-IC gap

8.1 Resolution and Maximum Rotating Speed

When using the AS5304/AS5306 in an off-axis rotary application, a multi-pole ring magnet must be used. Resolution, diameter and maximum speed depend on the number of pole pairs on the ring.

8.1.1 Resolution

The angular resolution increases linearly with the number of pole pairs. One pole pair has a resolution (= interpolation factor) of 160 steps or 40 quadrature pulses.

Resolution [steps] = ***[interpolation factor] x [number of pole pairs]***

Resolution [bit] = ***log (resolution[steps]) / log (2)***

Example: multi-pole ring with 22 pole pairs

Resolution = 160x22 = 3520 steps per revolution

= 40x22 = 880 quadrature pulses / revolution

= 11.78 bits per revolution = 0.1023° per step

8.1.2 Multi-pole Ring Diameter

The length of a pole pair across the median of the multi-pole ring must remain fixed at either 4mm (AS5304) or 2.4mm (AS5306). Hence, with increasing pole pair count, the diameter increases linearly with the number of pole pairs on the magnetic ring.

Magnetic ring diameter = ***[pole length] * [number of pole pairs] / π***

for AS5304: d = 4.0mm * number of pole pairs / π

for AS5306: d = 2.4mm * number of pole pairs / π

Example: same as above: multi-pole ring with 22 pole pairs for AS5304

Ring diameter = 4 * 22 / 3.14 = 28.01mm (this number represents the median diameter of the ring, this is where the Hall elements of the AS5304/AS5306 should be placed; see Figure 4)

For the AS5306, the same ring would have a diameter of: 2.4 * 22 / 3.14 = 16.8mm

8.1.3 Maximum Rotation Speed

The AS5304/AS5306 use a fast interpolation technique allowing an input frequency of 5kHz. This means, it can process magnetic field changes in the order of 5000 pole pairs per second or 300,000 revolutions per minute. However, since a magnetic ring consists of more than one pole pair, the above figure must be divided by the number of pole pairs to get the maximum rotation speed:

Maximum rotation speed = ***300,000 rpm / [number of pole pairs]***

Example: same as above: multi-pole ring with 22 pole pairs:

Max. speed = 300,000 / 22 = 13,636 rpm (this is independent of the pole length)

8.1.4 Maximum Linear Travelling Speed

For linear motion sensing, a multi-pole strip using equally spaced north and south poles is used. The pole length is again fixed at 2.0mm for the AS5304 and 1.2mm for the AS5306. As shown in 8.1.3 above, the sensors can process up to 5000 pole pairs per second, so the maximum travelling speed is:

Maximum linear travelling speed = ***5000 * [pole pair length]***

Example: linear multi-pole strip:

Max. linear travelling speed = 4mm * 5000 1/sec = 20,000mm/sec = 20m/sec for AS5304

Max. linear travelling speed = 2.4mm * 5000 1/sec = 12,000mm/sec = 12m/sec for AS5306

9 GENERAL DEVICE SPECIFICATIONS

9.1 Absolute Maximum Ratings (Non Operating)

Stresses beyond those listed under “Absolute Maximum Ratings“ may cause permanent damage to the device.

Parameter	Symbol	Min	Max	Unit	Note
Supply	VDD	-0.3	7	V	
Input pin voltage	V_{in}	VSS-0.5	VDD+0.5	V	
Input current (latchup immunity)	I_{scr}	-100	100	mA	Norm: JESD78
ESD		+/-2		kV	Norm: MIL 883 E method 3015
Package thermal resistance	Θ_{JA}		114.5	°C /W	Still Air / Single Layer PCB
Storage temperature	T_{strg}	-55	150	°C	
Soldering conditions	T_{body}		260	°C	Norm: IPC/JEDEC J-STD-020C
Humidity non-condensing		5	85	%	

9.2 Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit	Note
Positive supply voltage	AVDD	4.5	5.0	5.5	V	
Digital supply voltage	DVDD					
Negative supply voltage	VSS	0.0	0.0	0.0	V	
Power supply current, AS5304	IDD	25		35	mA	A/B/Index, AO unloaded!
Power supply current, AS5306		20		30		
Ambient temperature	T_{amb}	-40		125	°C	
Junction temperature	T_J	-40		150	°C	
Resolution	LSB		25		µm	AS5304
			15			AS5306
Integral nonlinearity	INL			1	LSB	Ideal input signal (ErrMax - ErrMin) / 2
Differential nonlinearity	DNL			±0.5	LSB	No missing pulses. optimum alignment
Hysteresis	Hyst	1	1.5	2	LSB	

9.3 System Parameters

Parameter	Symbol	Min	Max	Unit	Note
Power up time	T_{PwrUp}		500	µs	Amplitude within valid range / Interpolator locked, A B Index enabled
Propagation delay	T_{Prop}		20	µs	Time between change of input signal to output signal

9.4 A / B / C Push/Pull or Open Drain Output

Push Pull Mode is set for AS530xA, Open Drain Mode is set for AS530xB versions.

Parameter	Symbol	Min	Typ	Max	Unit	Note
High level output voltage	V_{OH}	0.8 VDD			V	Push/Pull mode
Low level output voltage	V_{OL}			0.4 + VSS	V	
Current source capability	I_{LOH}	12	14		mA	Push/Pull mode
Current sink capability	I_{LOL}	13	15		mA	
Short circuit limitation current	I_{Short}		25	39	mA	Reduces maximum operating temperature
Capacitive load	C_L		20		pF	See Figure 13
Load resistance	R_L		820		Ω	See Figure 13
Rise time	t_R			1.2	µs	Push/Pull mode
Fall time	t_F			1.2	µs	

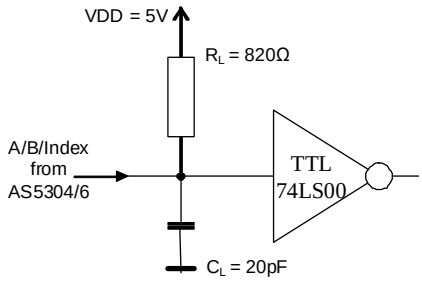


Figure 13: Typical digital load

9.5 CAO Analogue Output Buffer

Parameter	Symbol	Min	Typ	Max	Unit	Note
Minimum output voltage	$V_{OutRange}$	0.5	1	1.2	V	Strong field, min. AGC
Maximum output voltage	$V_{OutRange}$	3.45	4	4.3	V	Weak field, max. AGC
Offset	V_{Offs}			±10	mV	
Current sink / source capability	I_L	5			mA	
Average short circuit current	I_{Short}	6		40	mA	Reduces maximum Operating Temperature
Capacitive load	C_L		10		pF	
Bandwidth	BW		5		KHz	

9.6 Magnetic Input

Parameter	Symbol	Min	Typ	Max	Unit	Note
Magnetic pole length	L_{P_FP}		2.0		mm	AS5304
			1.2			AS5306
Magnetic pole pair length	T_{FP}		4.0		mm	AS5304
			2.4			AS5306
Magnetic amplitude	A_{mag}	5		60	mT	
Operating dynamic input range		1:12		1:24		
Magnetic offset	Off_{mag}			±0.5	mT	
Magnetic temperature drift	T_{dmag}			-0.2	%/K	
Input frequency	f_{mag}	0		5	kHz	

Table 1: AS5304 ordering guide

Device	Resolution	Magnet Pole Length	Digital Outputs
AS5304A	25µm	2mm	Push Pull
AS5304B	25µm	2mm	Open Drain

Table 2: AS5306 ordering guide

Device	Resolution	Magnet Pole Length	Digital Outputs
AS5306A	15µm	1.2mm	Push Pull
AS5306B	15µm	1.2mm	Open Drain

Contact

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11.8 Appendix I (Linear Motor Spec Sheet)

Cog-free Brushless Servo Motors

- Standard and custom magnetic track lengths
- Peak forces from 16N [3.6 Lbs] to 2300 N [517 Lbs]
- High acceleration to 98m/s^2 [10g's]
- High speeds to 10m/s [400 in/sec] with encoder resolutions ≥1 micron
- Speeds to 2.5m/s [100 in/sec] with encoder resolutions ≤ 1 micron
- High accuracy 2.5μm/300m [±0.0001 in/ft] (encoder dependent)
- High repeatability 1μm [0.00004 in] (encoder dependent)
- Unlimited stroke length
- Independent multiple coil operation with overlapping trajectories
- No metal-to-metal contact, virtually maintenance free
- Modular magnet tracks

The cog free motor is designed for unlimited stroke servo applications that require smooth operation without magnetic force variation or "cogging". A large range of motors are available to suit different applications. These motors are supplied in kit form to be integrated into your machine. They are used in closed loop servo systems and provide optimum performance.
For higher continuous forces, air and water cooling options are available.
Baldor's cog free motors are ideally suited for applications requiring high accuracy (with resolutions down to 0.1μm) and smooth movement.

The motors can be controlled from any of Baldor's 3 phase brushless drive family, including MicroFlex, FlexDrive-II, Flex+Drive-II and MintDrive-II. The motors are also compatible with the NextMove range of motion controllers for multi-axis position control.
Baldor's cog free linear motors are nickel plated meeting ROHS compliance.

Baldor provides standard magnetic track lengths to optimize pricing for customers. These standards include: LTCF-C24, LTCF-E24, LTCF-F24; and LTCF-C40, LTCF-E40, LTCF-F40.
Other track lengths are available as custom.

Ordering Information

Primary (Forcer)

L M C F ☐☐☐ - ☐☐☐☐

NO. OF POLES
02, 04...18

SIZE CODE mm [inch]
A = 40 [1.6]
B = 53.6 [2.11]
C = 57.2 [2.25]
D = 86.4 [3.4]
E = 114.3 [4.5]
F = 152.4 [6.0]

HALLS
H = Hall Effect Sensors
N = No Effect Sensors

COOLING TYPE
C = Convection
A = Air Cooling
W = Water

TERMINATION
O = Flying Leads (3m/10 ft. Std.)

WINDING
Blank = Standard
P = Parallel

Secondary (Magnet Track)

L T C F - ☐☐☐

SIZE CODE mm [inch]
A = 40.7 [1.6]
B = 53.6 [2.11]
*C = 57.2 [2.25]
D = 86.4 [3.4]
*E = 114.3 [4.5]
*F = 152.4 [6.0]

CODE FOR LENGTH OF MODULAR TRACK mm [inch]
04 = 121.9 [4.8]
07 = 182.9 [7.2]
09 = 243.8 [9.6]
12 = 304.8 [12]
* 24 = 609.6 [24]
* 40 = 1036 [40.8]

* Indicates standard size and length

Cog-free Brushless Technical Data

Technical Data

Catalog Numbers	Continuous Force (1) - (2) - (3)		Continuous Current	Peak Force @ 10% Duty		Peak Current @ 10% Duty	Back-EMF Constant K_{emf} (ph-ph)	
	N	Lbs	Amps	N	Lbs	Amps	V/m/sec	V/in/sec
LMCF02A-HCO	5.3	1.2	1.7	16	3.6	5.1	3.1	0.08
LMCF02B-HCO	13.8	3.1	2.1	41.8	9.4	6.3	6.7	0.17
LMCF04B-HCO	27.8	6.2	2.1	83.3	18.7	6.3	13.2	0.34
(4) LMCF02C-HCO	29	6.5	1.9	86.8	19.5	5.7	15.2	0.39
(4) LMCF04C-HCO	58	13	1.9	173	39	5.7	30.4	0.77
(4) LMCF06C-HCO	87	19.5	1.9	260	58	5.7	45.6	1.16
(4) LMCF08C-HCO	116	26	1.9	347	78	5.7	60.9	1.55
LMCF02D-HCO	36.8	8.3	1.5	110	24	4.4	24.8	0.63
LMCF04D-HCO	73.6	16.5	1.5	220	49	4.4	49.6	1.26
LMCF06D-HCO	110	24.8	1.5	330	74	4.4	74.4	1.89
LMCF08D-HCO	147	33	1.5	440	99	4.4	99.3	2.52
LMCF10D-HCO	184	41.3	3.0	550	123	8.9	61.8	1.57
LMCF12D-HCO	220	49.6	3.0	660	148	8.9	74.2	1.88
(4) LMCF04E-HCO	124	28	1.6	372	84	4.7	79.9	2.03
(4) LMCF06E-HCO	185	42	3.1	556	125	9.2	59.7	1.52
(4) LMCF08E-HCO	251	56	3.1	753	169	9.2	82.0	2.08
(4) LMCF10E-HCO	314	70	3.1	942	212	9.2	102.5	2.60
(4) LMCF12E-HCO	377	85	3.1	1132	254	9.2	123.0	3.12
(4) LMCF14E-HCO	440	99	3.1	1318	294	9.2	143.5	3.64
(4) LMCF04F-HCO	191	43	2.6	578	130	7.8	74.4	1.89
(4) LMCF08F-HCO	387	87	2.6	1152	256	7.8	148.4	3.78
(4) LMCF12F-HCO	578	130	3.9	1726	338	11.6	148.4	3.77
(4) LMCF16F-HCO	771	173	5.2	2300	517	15.6	148.0	3.76

Notes: All specifications are for reference only.

Technical data at 75°C rise over 25°C ambient.

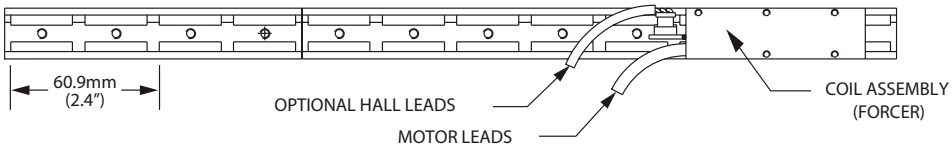
(**1**) Addition of 254 x 254 x 25.4 mm [10 x 10 x 1 in] aluminum heat sink increases continuous force capability by 20% (along with 20% more current).

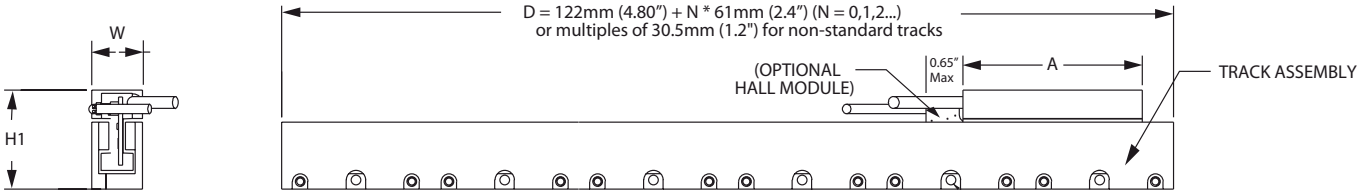
(**2**) Addition of forced air cooling increases continuous force 12% (and 12% more current).

(**3**) Liquid cooling option increases continuous forces by 25% and power dissipation by 50%. Available only on motors with D, E and F "size codes."

(**4**) Standard Motor

Cog-free Brushless Motors Dimensions





Track assemblies can be stacked for additional stroke lengths.

Forcer/Primary (Coil Assembly) - LMCF

Catalog Number	A		W		H1		Weight	
	mm	in	mm	in	mm	in	Kg	Lbs
Size A								
LMCFO2A-HCO	73.7	2.90	20.8	0.82	40.64	1.60	0.08	0.17
Size B								
LMCFO2B-HCO	73.7	2.90	20.83	0.82	53.59	2.11	0.11	0.25
LMCFO4B-HCO	134.6	5.30	20.83	0.82	53.59	2.11	0.22	0.49
Size C								
LMCFO2C-HCO	73.7	2.90	30.48	1.20	57.15	2.25	0.18	0.39
LMCFO4C-HCO	134.6	5.30	30.48	1.20	57.15	2.25	0.32	0.70
LMCFO6C-HCO	195.6	7.70	30.48	1.20	57.15	2.25	0.57	1.25
LMCFO8C-HCO	256.5	10.10	30.48	1.20	57.15	2.25	0.75	1.64
Size D								
LMCFO2D-HCO	73.7	2.90	34.29	1.35	86.31	3.40	0.35	0.76
LMCFO4D-HCO	134.6	5.30	34.29	1.35	86.31	3.40	0.6	1.4
LMCFO6D-HCO	195.6	7.70	34.29	1.35	86.31	3.40	0.9	2.0
LMCFO8D-HCO	256.5	10.10	34.29	1.35	86.31	3.40	1.2	2.6
LMCF10D-HCO	317.5	12.50	34.29	1.35	86.31	3.40	1.5	3.2
LMCF12D-HCO	378.5	14.90	34.29	1.35	86.31	3.40	1.8	3.9
Size E								
LMCFO4E-HCO	134.6	5.30	39.37	1.55	114.3	4.50	0.77	1.7
LMCFO6E-HCO	195.6	7.70	39.37	1.55	114.3	4.50	1.1	2.5
LMCFO8E-HCO	256.5	10.10	39.37	1.55	114.3	4.50	1.5	3.2
LMCF10E-HCO	317.5	12.50	39.37	1.55	114.3	4.50	1.8	4.0
LMCF12E-HCO	378.5	14.90	39.37	1.55	114.3	4.50	2.2	4.8
LMCF14E-HCO	439.4	17.30	39.37	1.55	114.3	4.50	2.5	5.6
Size F								
LMCFO4F-HCO	156.2	5.30	44.0	1.73	152.4	6.00	1.65	3.6
LMCFO8F-HCO	256.5	10.10	44.0	1.73	152.4	6.00	3.1	6.8
LMCF12F-HCO	378.5	14.90	44.0	1.73	152.4	6.00	4.5	9.9

Secondary (Track) - LTCF

Standard cog-free tracks include:	
610 mm (24inch)	**1036 mm (40.8 inch)**
LTCF-C24	**LTCF-C40**
LTCF-E24	**LTCF-E40**
LTCF-F24	**LTCF-F40**

Other track lengths are available as custom

Catalog Number	D	
	mm	in
LTCF-X04	122	4.8
LTCF-X07	183	7.2
LTCF-X09	244	9.6
LTCF-X12	305	12.0
LTCF-X24	610	24.0
LTCF-X40	1036	40.8

Catalog Number	Weight	
	Kg/m	Lb/in
LTCF-AXX	3.6	0.20
LTCF-BXX	5.5	0.31
LTCF-CXX	8.1	0.45
LTCF-DXX	11.6	0.65
LTCF-EXX	17.2	0.96
LTCF-FXX	34	1.90

NOTE: Min track length recommended = "A" dimension + 0.65 inch [1.65mm] + stroke [min 3 inch (76.2mm)]

11.9 Appendix J (Data Acquisition Spec Sheet)

ECONseries
Low Cost USB Data Acquisition Modules

The ECONseries is a flexible yet economical series of multifunction data acquisition modules. You choose the number of analog I/O and digital I/O channels, the resolution you need, and the signal range of your application.

Key Features:

- **Ultimate flexibility** with up to 24 analog inputs, 2 analog outputs, 28 digital I/O, and one 32-bit counter timer
- **10-, 12-, or 16-bit resolution**
- **Independent subsystem operation** at throughput rates up to 750 kHz per channel
- **Simultaneous analog inputs** on the DT9816 modules
- **Signal range of ±10V** on both the analog input and analog output, DT9812-2.5V has analog signal range of 0-2.44V
- **Generate sine, rectangle, triangle, or DC waveforms** with the analog outputs
- **Three versions of Digital I/O** modules: isolated, non-isolated, and high current drive
- **Monitor and control** up to 28 digital I/O lines
- **Perform event counting,** frequency measurement, edge-to-edge measurement, and rate generation (continuous pulse output) operations using 32-bit counter/timer
- **Shielded, rugged enclosure** for noise immunity, with built-in screw terminals

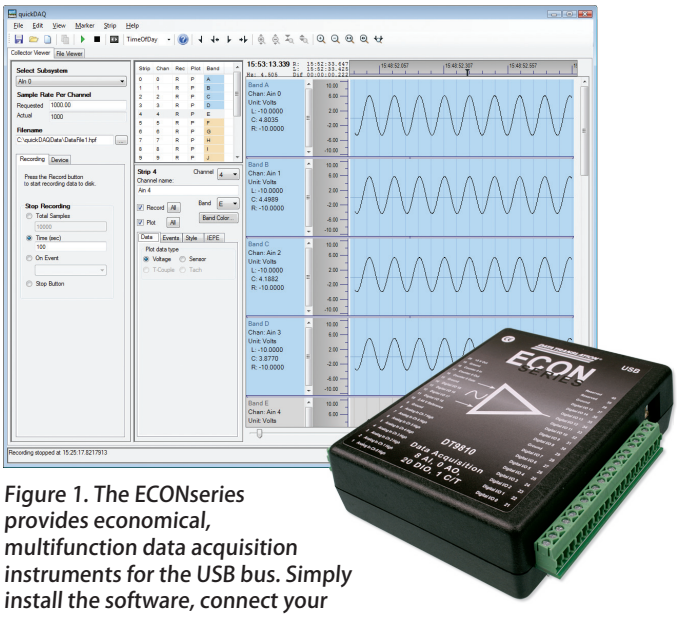


Figure 1. The ECONseries provides economical, multifunction data acquisition instruments for the USB bus. Simply install the software, connect your module to any USB port, and measure.

- **Easy signal connections on the DT9812-10V-OEM and the DT9816-OEM** with two 20-pin connectors for all I/O signals
- **All modules** run off USB power supply, no external power supply needed

Features Summary								
Module	**Analog Inputs**	**Resolution**	**I/O Range**	**Analog Input Sample Rate**	**Analog Outputs**	**Analog Output Update Rate**	**Digital I/O**	**C/T**
DT9810	8 SE	10-bit	0 to 2.44V	25 kS/s aggregate	—	—	20 I/O	1
DT9812-2.5V	8 SE	12-bit	0 to 2.44V, 1.22V, 0.61V, 0.305V, 0.1525V	50 kS/s aggregate	2	50 kS/s	8 in/8 out	1
DT9812-10V*	8 SE	12-bit	±10V, ±5V, ±2.5V, ±1.25V	50 kS/s aggregate	2	50 kS/s	8 in/8 out	1
DT9812A	8 SE	12-bit	±10V, ±5V, ±2.5V, ±1.25V	100 kS/s aggregate	2	75 kS/s	8 in/8 out	1
DT9813-10V	16 SE	12-bit	±10V, ±5V, ±2.5V, ±1.25V	50 kS/s aggregate	2	50 kS/s	4 in/4 out	1
DT9813A	16 SE	12-bit	±10V, ±5V, ±2.5V, ±1.25V	100 kS/s aggregate	2	75 kS/s	4 in/4 out	1
DT9814-10V	24 SE	12-bit	±10V, ±5V, ±2.5V, ±1.25V	50 kS/s aggregate	2	50 kS/s	—	1
DT9814A	24 SE	12-bit	±10V, ±5V, ±2.5V, ±1.25V	100 kS/s aggregate	2	75 kS/s	—	1
DT9816*	6 SE	16-bit	±10V or ±5V	50 kS/s per ch	—	—	8 in/8 out	1
DT9816-A	6 SE	16-bit	±10V or ±5V	150 kS/s per ch	—	—	8 in/8 out	1
DT9816-S	6 SE	16-bit	±10V or ±5V	750 kS/s per ch	—	—	8 in/8 out	1
DT9817	—	—	—	—	—	—	28 I/O	1
DT9817-H	—	—	—	—	—	—	28 I/O High Drive	1
DT9817-R	—	—	—	—	—	—	8 in/8 out Isolated High Drive	1

*** OEM version available.**

DT9812 Block Diagram

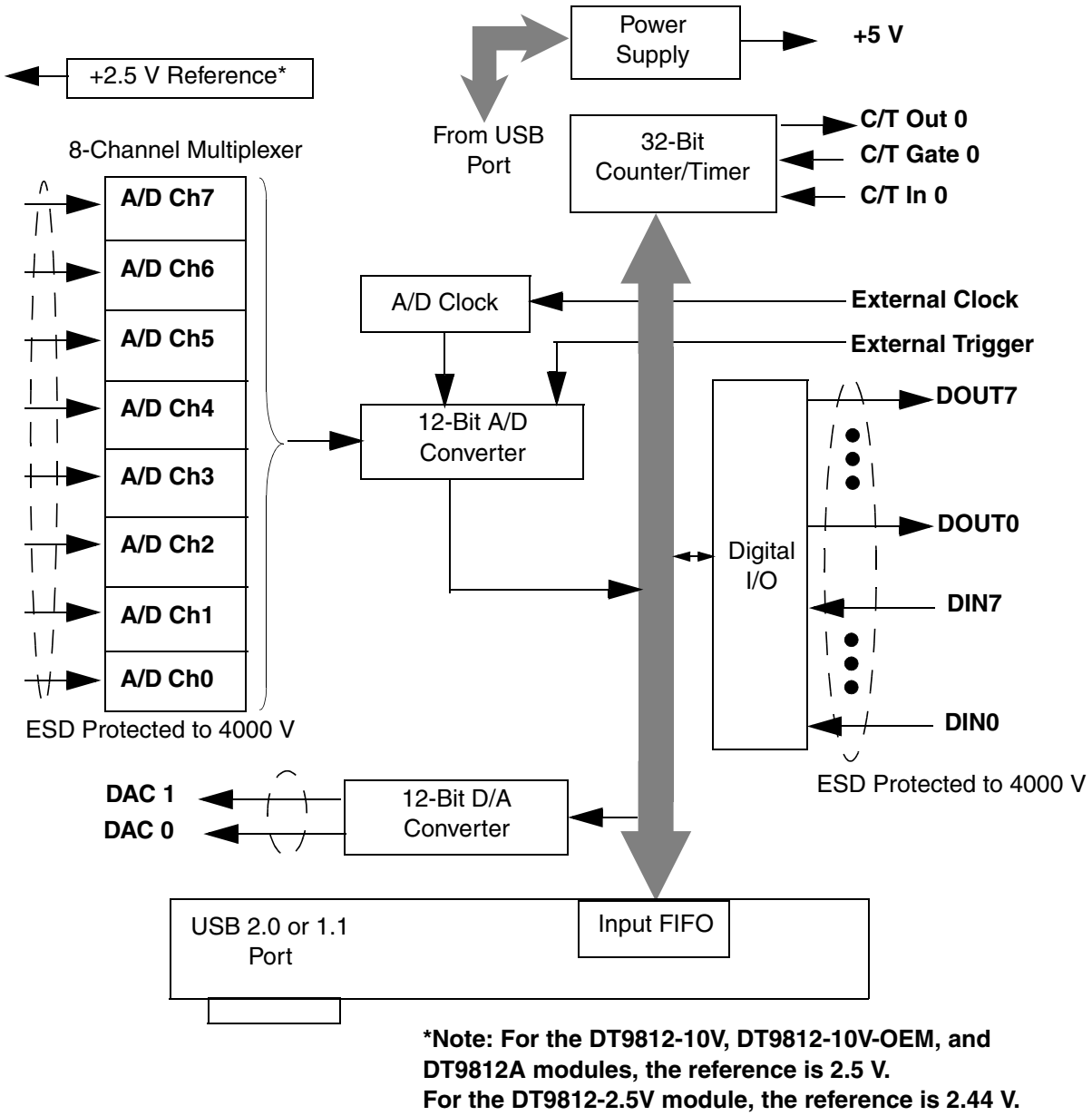


Figure 2. Block Diagram of the DT9812-2.5V, DT9812-10V, DT9812-10V-OEM, and DT9812A Modules.

DT9816 Series Block Diagram

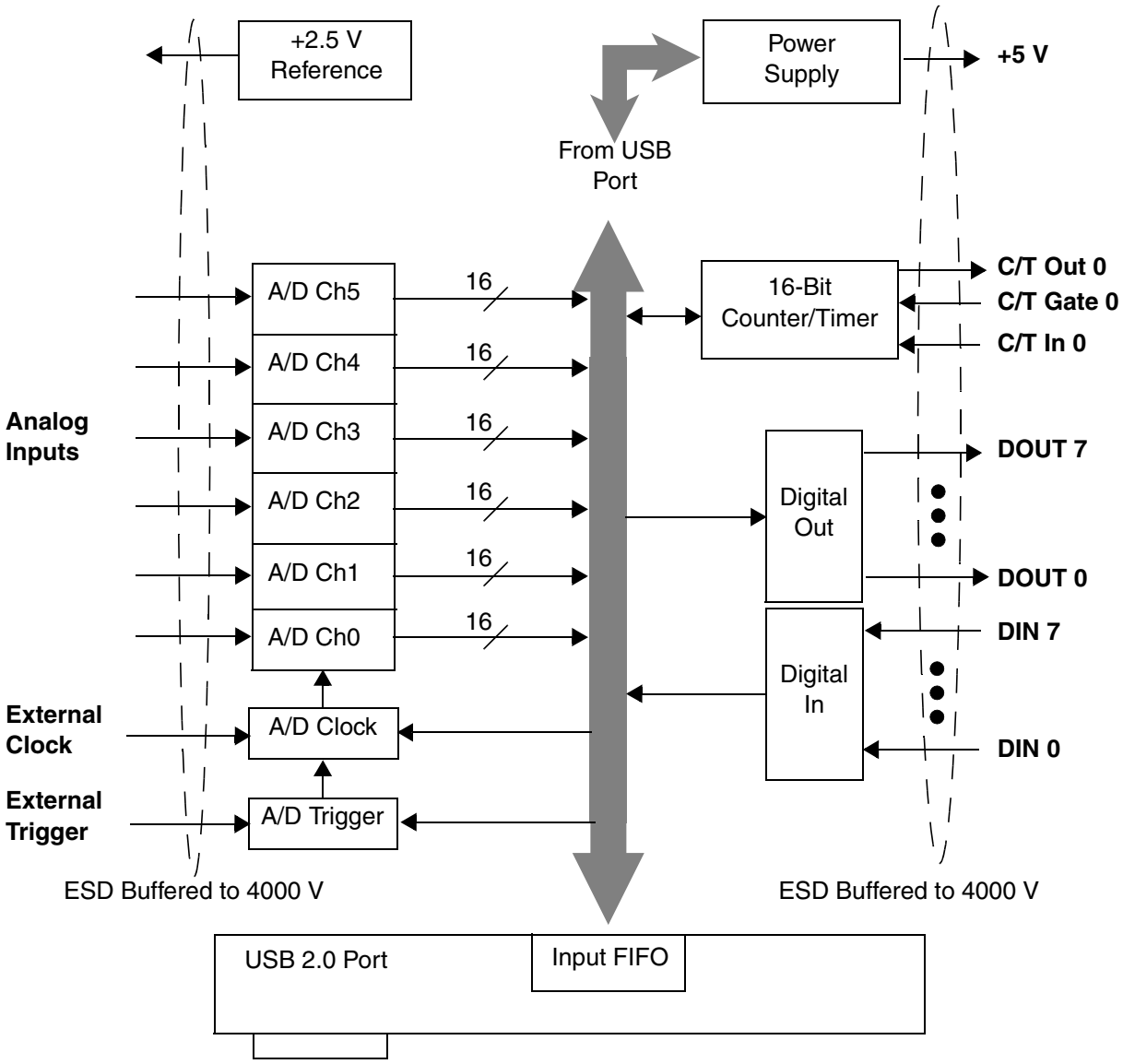


Figure 3. Block Diagram of the DT9816 Series Modules.

Figure 4. Connect to a host computer using the standard USB 1.1 or 2.0 plug-in connector on the ECONseries module. The USB connector provides power to the module, eliminating the need for an external power supply, while providing complete enumeration for all data flow.

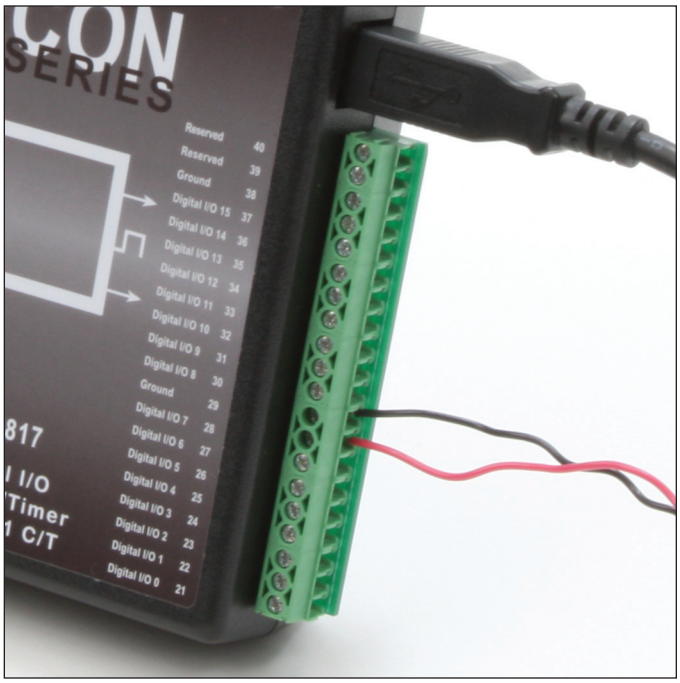


Figure 5. Connect sensors directly to the screw terminal of the module. Screw terminals can accept AWG 26 to AWG 16 size wire.

Easy to Hook-up

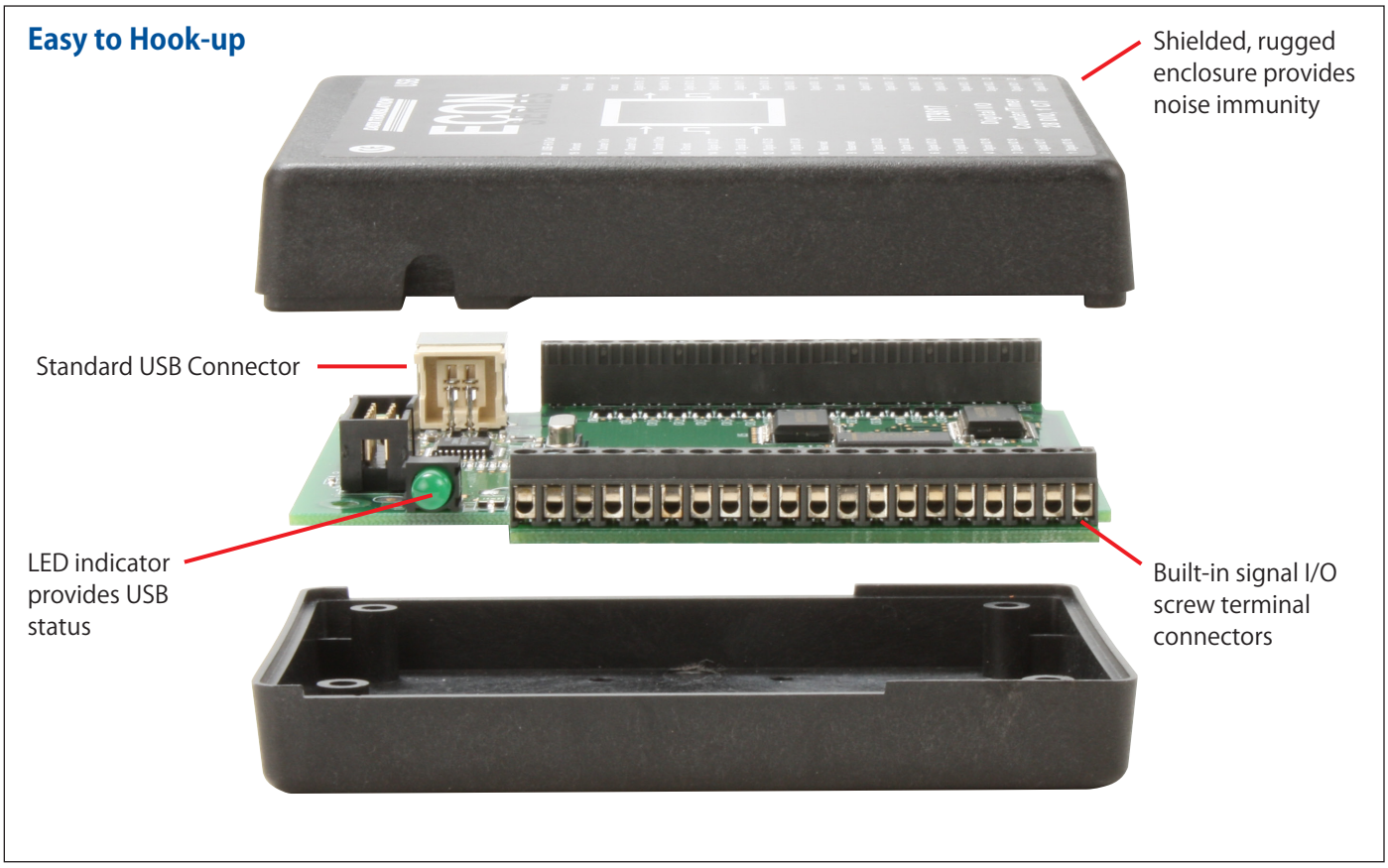

Shielded, rugged enclosure provides noise immunity
Standard USB Connector
LED indicator provides USB status
Built-in signal I/O screw terminal connectors

Figure 6. ECONseries modules provide easy signal and USB connections in a shielded, rugged enclosure.

ECONseries Design Advantages

Prevents Measurement Errors

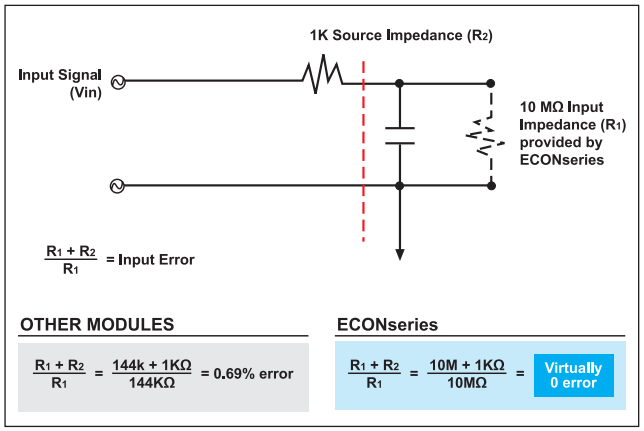

1K Source Impedance (R2)
Input Signal (Vin)
10 MΩ Input Impedance (R1) provided by ECONseries
R1 + R2 / R1 = Input Error
OTHER MODULES
R1 + R2 / R1 = 144k + 1KΩ / 144KΩ = 0.69% error
ECONseries
R1 + R2 / R1 = 10M + 1KΩ / 10MΩ = Virtually 0 error

Figure 7. The ECONseries provides 10 MOhms of input impedance for virtually error-free analog input measurements.

Operates Reliably

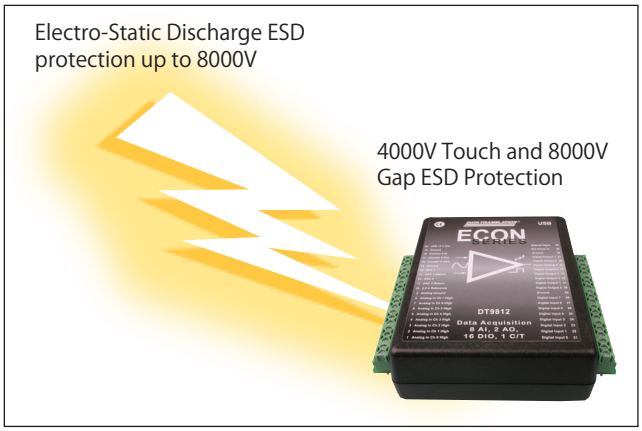


Figure 8. The ECONseries provides 4000 V touch and 8000 V gap ESD protection circuitry for superior noise immunity.

Performs Simultaneous Operations

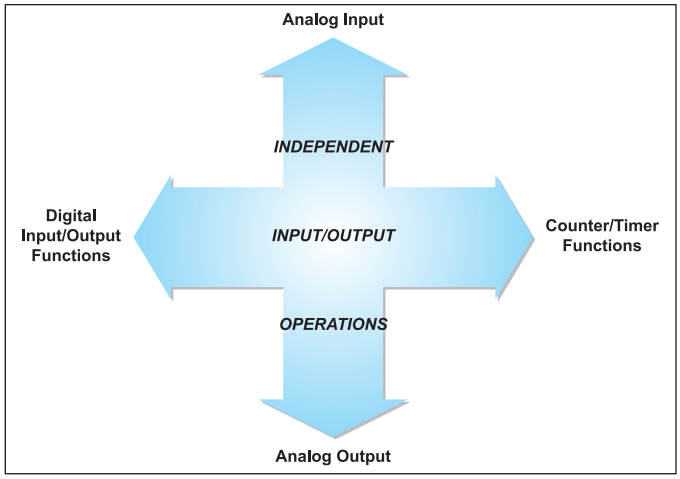


Figure 9. The ECONseries provides 4000 V touch and 8000 V gap ESD protection circuitry for superior noise immunity.

Prevents Measurement Errors

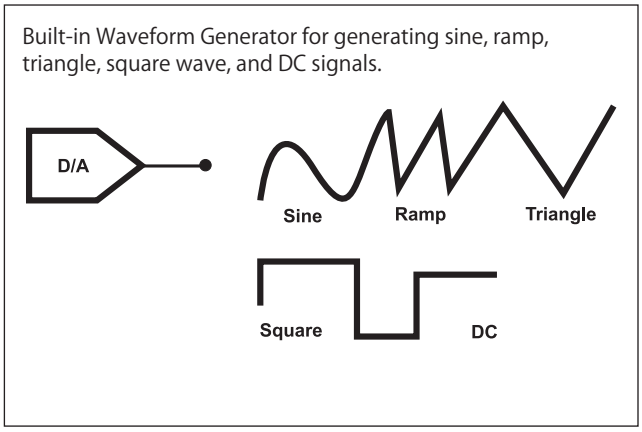


Figure 10. The DT9812-2.5 V, DT9812-10V, DT9813-10V, and the DT9814-10V modules provide 2 waveform DACs for generating sine, ramp, triangle, square wave, and DC signals.

Detects Edges for Pulse Width, Frequency, and Period Measurements

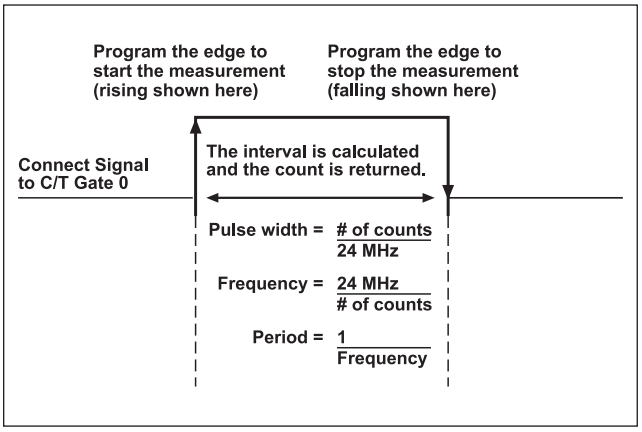

Program the edge to start the measurement (rising shown here)
Program the edge to stop the measurement (falling shown here)
Connect Signal to C/T Gate 0
The interval is calculated and the count is returned.
Pulse width = # of counts / 24 MHz
Frequency = 24 MHz / # of counts
Period = 1 / Frequency

Figure 11. Programmable edges allow you to use the counter/timer of an ECONseries module to measure the pulse width, frequency, and period of a signal.

DT9816 Design Advantages

Six Simultaneously Sampled Analog Inputs

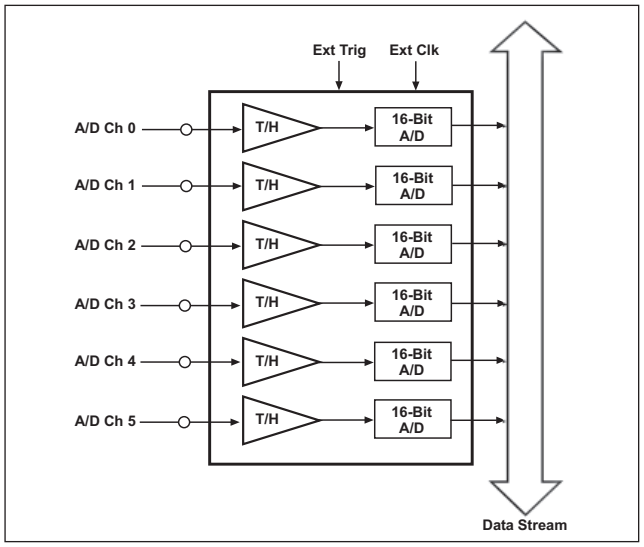


Figure 12. The DT9816 modules feature six, independent, successive-approximation A/D converters with track-and-hold circuitry. Each converter uses a common clock and trigger for simultaneous sampling of all six analog input signals. The throughput rate varies depending on the model you choose.

Accurate Measurements Designed In

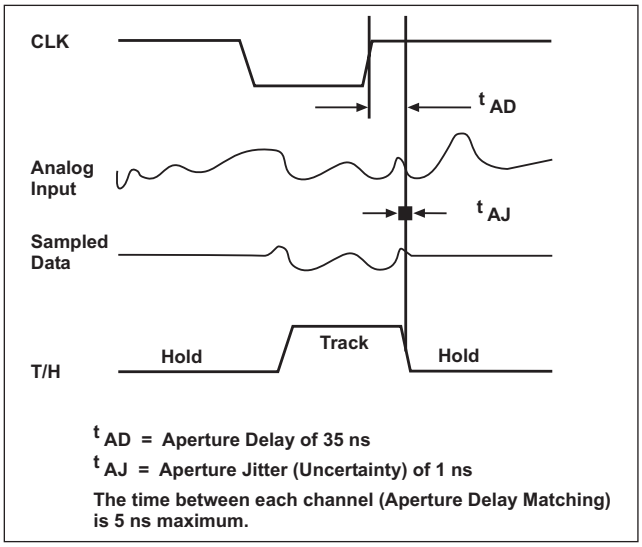


Figure 13. The A/D design of the DT9816 modules feature built-in accuracy. A maximum aperture delay of 35 ns (the time that it takes the A/D to switch from track to hold mode) is well matched at 5 ns across all six track-and-hold circuits, virtually eliminating the channel-to-channel skew that is associated with multiplexed inputs. A maximum aperture uncertainty of 1 ns (the jitter or variance in aperture delay), virtually eliminates phase noise in your data.

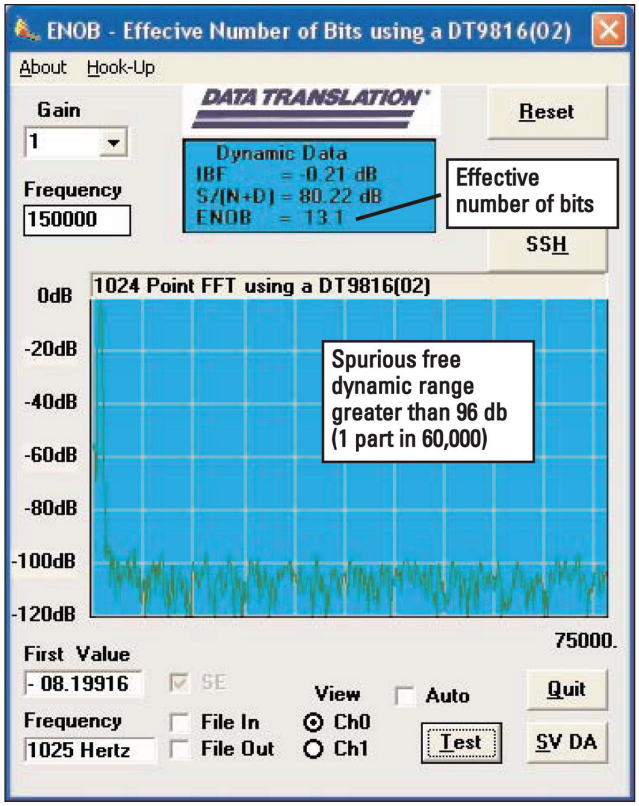


Figure 14. This graph shows the outstanding quality of the DT9816-A for all error sources ... effective number of bits greater than 13.1 from all sources. Note the absence of harmonic content and digital switching noise across the full spectrum.

Key Features of the DT9816:

- High-Speed Simultaneous Acquisition – Acquire all six analog input channels simultaneously at up to 50 kHz per channel (DT9816), 150 kHz per channel (DT9816-A), or 750 kHz per channel (DT9816-S).
- Input -3dB bandwidth is 4 MHz typical (DT9816, DT9816-A), 40 MHz typical (DT9816-S)
- High-Resolution Data – 16-bit resolution for precision measurements.
- Two Bipolar Input Ranges – Input range of ±10 V and ±5 V signal for maximum flexibility.
- Digital I/O Functions – 8 fixed digital outputs for controlling external equipment.
- Multifunction Counter/Timer – One 16-bit counter/timer for event counting, frequency measurement, and continuous pulse output operations.

Analog Inputs

The DT9810 provides 10-bit resolution, while the DT9812, DT9813, and DT9814 modules provide 12-bit resolution. For maximum resolution, the DT9816 modules provide 16-bit resolution.

The DT9810 and DT9812 modules provide eight single-ended analog input channels. The DT9813 modules provide 16 single-ended analog inputs. The DT9814 modules provide 24 single-ended analog input channels. The modules can acquire data from a single analog input channel or from a group of analog input channels.

DT9810 and DT9812-2.5V modules feature a full-scale input signal range of 0 to 2.44 V. If you need a full-scale input signal range of ±10 V, the DT9812, DT9813, DT9814, and DT9816 modules are available. The DT9816 modules also feature a full-scale input signal range of ± 5 V.

The DT9812-2.5V provides gains of 1, 2, 4, 8, and 16; the DT9812, DT9813, and DT9814 modules provide programmable gains of 1, 2, 4, and 8; and the DT9816 modules provide gains of 1 and 2.

Effective Input Range			
Module	**Gain**	**Unipolar Input Range**	**Bipolar Input Range**
DT9812-2.5V	1	0 to 2.44 V	—
	2	0 to 1.22 V	—
	4	0 to 0.610 V	—
	8	0 to 0.305 V	—
	16	0 to 0.1525 V	—
DT9812-10V DT9812A DT9813-10V DT9813A DT9814-10V DT9814A	1	—	±10 V
	2	—	±5 V
	4	—	±2.5 V
	8	—	±1.25 V

Throughput

Before selecting a module, consider whether you need analog inputs, and if so, what kind of throughput you need.

Modules with multiplexed inputs, such as the DT9810, DT9812, DT9813, and DT9814 modules provide only one A/D converter that is shared by the inputs. A multiplexer selects or switches the channel to acquire, which introduces a settling time and phase shift between channels. In a multiplexed architecture, the total or aggregate throughput is the maximum rate of the sampling clock. The DT9810 provides an aggregate throughput of up 25 kHz, while the DT9812-2.5V, DT9812-10V, DT9813-10V, and DT9814-10V provide an aggregate throughput of up to 50 kHz, and the DT9812A, DT9813A, and DT9814A provide an aggregate throughput of up to 100 kHz. The per channel rate is determined by dividing the maximum sampling rate by the number of inputs sampled. For example, if you are acquiring 8 inputs on a DT9812-10V, the per channel rate is 6.25 kS/s.

In contrast, modules that provide separate A/D converters per channel, such as the DT9816, DT9816-A, and DT9816-S, eliminate the phase shift between signals, allowing you to correlate simultaneous measurements of multiple inputs. The per channel sampling rate, in this case, is the maximum rate of the sampling clock (50 kS/s for the DT9816, 150 kS/s for the DT9816-A, and 750 kS/s for the DT9816-S).

According to sampling theory (Nyquist Theorem), specify a frequency that is at least twice as fast as the input's highest frequency component. For example, to accurately sample a 2 kHz signal, specify a sampling frequency of at least 4 kHz. Doing so avoids an error condition called aliasing, in which high frequency input components erroneously appear as lower frequencies after sampling.

Input Triggers

A trigger is an event that occurs based on a specified set of conditions. Acquisition starts when the module detects the initial trigger event and stops when the buffers on the queue have been filled or when you stop the operation.

The DT9812, DT9813, DT9814, and DT9816 Series modules support the following trigger sources:

- **Software trigger** – A software trigger event occurs when the analog input operation is started (the computer issues a write to the module to begin conversions). Using software, specify the trigger source as a software trigger.
- **External digital (TTL) trigger** – An external digital (TTL) trigger event occurs when the module detects a high-to-low (negative) transition on the Ext Trigger In signal connected to the module. Using software, specify an external, negative digital (TLL) trigger.

Analog Outputs

DT9812, DT9813, and DT9814 Series modules provide two 12-bit analog output channels (DACs). The modules can output data from a single analog output channel or from both analog output channels.

The DT9812-2.5V module provides a fixed output range of 0 to 2.44. The DT9812-10V, DT9812-10V-OEM, DT9812A, DT9813-10V, DT9813A, DT9814-10V, and DT9814A modules provide a fixed output range of ±10 V. Through software, specify the range for the entire analog output subsystem (0 to 2.44 V for the DT9812-2.5 V module or ± 10 V for the DT9812-10V, DT9812-10V-OEM, DT9812A, DT9813-10V, DT9813A, DT9814-10V, and DT9814A modules), and specify a gain of 1 for each channel.

Output Trigger

A trigger is an event that occurs based on a specified set of conditions. The DT9812, DT9813, and DT9814 Series modules support a software trigger for starting analog output operations. Using a software trigger, the module starts outputting data when it receives a software command.

Waveform Generation

Generate sine, rectangle, triangle, or DC waveforms from one or both analog output channels. You can select the frequency, amplitude, duty, and offset cycle of the signal. For the DT9812-10V, DT9812-10V-OEM, DT9813-10V, DT9814-10V, the output frequency ranges between 30 Hz and 50 kHz. For the DT9812A, DT9813A, and DT9814A, the output frequency ranges between 30 Hz and 75 kHz.

Digital I/O Lines

The DT9812 Series modules provide 8 dedicated digital input lines and 8 dedicated digital output lines. The DT9813 Series modules provide 4 dedicated digital input lines and 4 dedicated digital output lines. The DT9814 Series modules do not support digital I/O operations.The DT9812-2.5V, DT9812-10V, DT9816, DT9816-A, and DT9816-S modules feature 8 digital input lines and 8 digital output lines. The DT9813-10V provides 4 digital input lines, and 4 digital output lines.

The DT9810 module provides 20 programmable digital I/O lines. If you need more digital I/O lines and do not need analog I/O functionality, select the DT9817 or DT9817-H module, which provide 28 programmable digital I/O lines. The DT9810 and DT9817 can source 4.5 mA and sink 10 mA. The DT9817-H provides high-drive capability, and can source 15 mA and sink 64 mA.

The DT9817-R is a high-performance relay version of the DT9817, and can switch up to 30 V at 400 mA. The DT9817-R features 8 dedicated digital input lines and 8 dedicated digital output lines. This module includes channel-to-channel isolation of up to 500 V (250 V between digital input channels that are paired in an opto-isolator). The DT9817-H and DT9817-R are ideal for solid state or mechanical relays.

Multifunction Counter/Timers

The DT9816 modules support one 16-bit counter/timer channel. All other modules feature one 32-bit counter/timer (16 bits in rate generation mode). The counter accepts a C/T clock input signal (pulse input signal) and gate input signal, and outputs a pulse signal (clock output signal). You can perform event counting, frequency measurement, edge-to-edge measurement (not supported by DT9816 modules), and rate generation (continuous pulse output) operations using this counter/timer.

Synchronizing Multiple Modules

You can synchronize the analog input operations of multiple DT9812, DT9813, DT9814, and DT9816 Series modules by connecting the output of the counter/timer from one module to the clock input of the next module as shown in Figure 15.

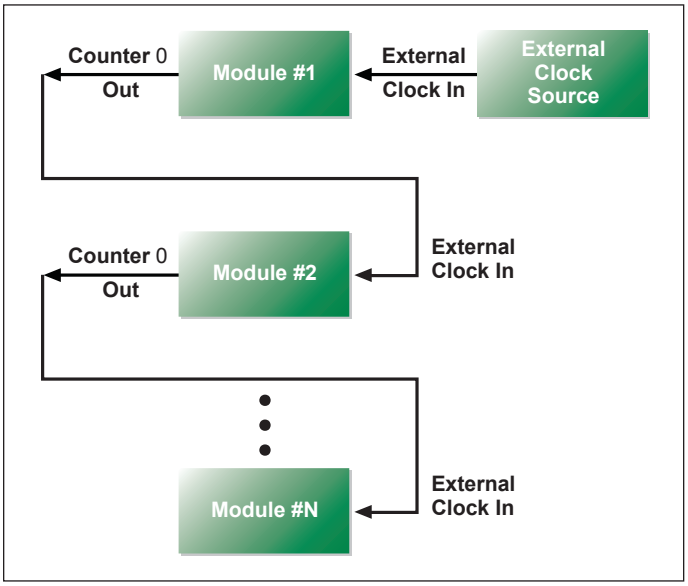


Figure 15. You can synchronize the analog I/O operations of multiple modules by connecting them together.

Easy Signal Connections

Built-in screw terminals on the module allow easy and direct signal connections. No extra accessories are required. Simply wire your signals to the module and you're all set.
For OEM users, the board-only versions of the DT9812-10V-OEM and DT9816-OEM provide two, 20-pin connectors to accommodate all I/O signals.

Software Options

Many software choices are available for application development, from ready-to-measure applications to programming environments.

The following software is available for use with all USB modules and is provided on the Data Acquisition Omni CD:

- **ECONseries Device Drivers** – The device driver allows the use of the USB DAQ module with any of the supported software packages or utilities.
- **quickDAQ application** – An evaluation version of this .NET application is included on the Data Acquisition Omni CD. quickDAQ acquires analog data from all devices supported by DT-Open Layers for .NET software at high speed, plots it during acquisition, analyzes it, and/or saves it to disk for later analysis. *Note: quickDAQ supports analog input functions only. DT9817 and DT9835 modules are DIO only and are not supported.*
- **Quick DataAcq application** – The Quick DataAcq application provides a quick way to get up and running using an ECONseries module. Using this application, verify key features of the module, display data on the screen, and save data to disk.
- **DT-Open Layers® for .NET Class Library** – Use this class library if you want to use Visual C#® or Visual Basic® for .NET to develop application software for an ECONseries module using Visual Studio® 2003/2005/2008; the class library complies with the DT-Open Layers standard.
- **DataAcq SDK** – Use the Data Acq SDK to use Visual Studio 6.0 and Microsoft® C or C++ to develop application software for an ECONseries module using Windows®; the DataAcq SDK complies with the DT-Open Layers standard.
- **DTx-EZ** – DTx-EZ provides ActiveX® controls, which allows access to the capabilities of an ECONseries module using Microsoft Visual Basic or Visual C++®; DTx-EZ complies with the DT-Open Layers standard.
- **DAQ Adaptor for MATLAB** – Data Translation's DAQ Adaptor provides an interface between the MATLAB® Data Acquisition (DAQ) toolbox from The MathWorks™ and Data Translation's DT-Open Layers architecture.
- **LV-Link** – This software is included on the Data Acquisition Omni CD. Use LV-Link to use the LabVIEW™ graphical programming language to access the capabilities of an ECONseries module.

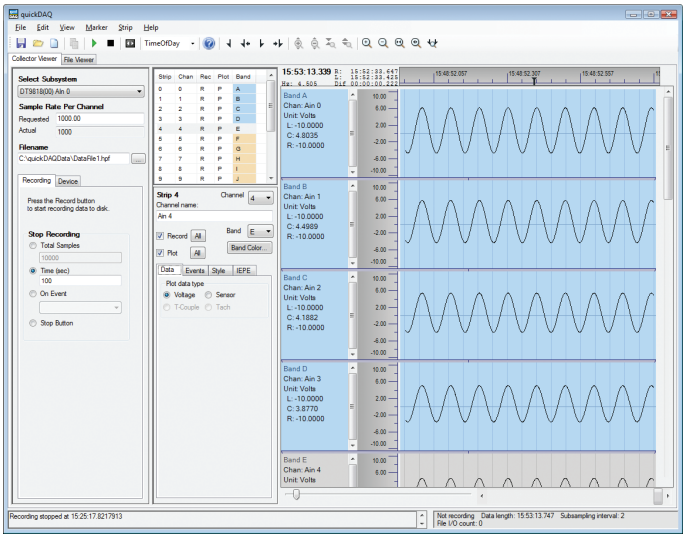


Figure 16. quickDAQ acquires analog data from all devices supported by DT-Open Layers for .NET software at high speed, plots it during acquisition, analyzes it, and/or saves it to disk for later analysis.

Cross-Series Compatibility

Virtually all Data Translation data acquisition boards, including the ECONseries, are compatible with the DT-Open Layers for .NET Class Library. This means that if your application was developed with one of Data Translation's software products, you can easily upgrade to a new Data Translation board. Little or no programming is needed.

User Manual

Each data acquisition module includes a user's manual that provides getting started and reference information. The manual is provided in electronic (PDF) format on the Data Acquisition Omni CD provided with the module.

Technical Support

Application engineers are available by phone and email during normal business hours to discuss your application requirements. Extensive product information, including drivers, example code, pinouts, a searchable Knowledge Base, and much more, is available 24 hours a day on our web site at www.datatranslation.com.

Ordering Information

All Data Translation hardware products are covered by a 1-year warranty. For pricing information, please visit our website or contact your local reseller.

MODULES:

- DT9810
- DT9812-2.5V
- DT9812-10V
- DT9812-10V-OEM
- DT9812A
- DT9813 -10V
- DT9813A
- DT9814 -10V
- DT9814A
- DT9816
- DT9816-OEM
- DT9816-A
- DT9816-S
- DT9817
- DT9817-H
- DT9817-R

ACCESSORIES:

- DIN Mount Kit

SYSTEM REQUIREMENTS:

- Windows XP, Windows Vista, or Windows 7
- Available USB Port(s) (2.0 or 1.1)
- CD-ROM drive

SOFTWARE OPTIONS:

- quickDAQ – High-performance, ready-to-run application that lets you acquire, plot, analyze, and save data to disk at up to 2 MHz per channel. SP8501-CD

FREE SOFTWARE:

- DAQ Adaptor for MATLAB – Access the analyzation and visualization tools of MATLAB.
- LV-Link – Access the power of Data Translation boards through LabVIEW.

For more information about the ECONseries modules, please visit:
http://www.datatranslation.com/info/ECONseries/

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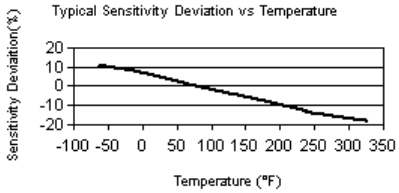
Prices, availability, and specifications are subject to change without notice.

11.10 Appendix K (Accelerometer Spec Sheet)

Model Number **356A24**	**ACCELEROMETER, ICP®, TRIAXIAL**	Revision E ECN #: 32784

Performance	**ENGLISH**	**SI**	
Sensitivity (±15 %)	10 mV/g	1.02 mV/(m/s²)	
Measurement Range	±500 g pk	±4905 m/s² pk	
Frequency Range (±5 %)	1 to 9000 Hz	1 to 9000 Hz	
Frequency Range (±10 %)	0.5 to 12000 Hz	0.5 to 12000 Hz	
Resonant Frequency	≥45 kHz	≥45 kHz	
Broadband Resolution (1 to 10000 Hz)	0.004 g rms	0.04 m/s² rms	[1]
Non-Linearity	≤1 %	≤1 %	[3]
Transverse Sensitivity	≤5 %	≤5 %	
Environmental			
Overload Limit (Shock)	±10000 g pk	±98100 m/s² pk	
Temperature Range (Operating)	-65 to +250 °F	-54 to +121 °C	[2][2]
Electrical			
Excitation Voltage	18 to 30 VDC	18 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤200 Ohm	≤200 Ohm	
Output Bias Voltage	7 to 11 VDC	7 to 11 VDC	
Discharge Time Constant	1.0 to 3.5 sec	1.0 to 3.5 sec	
Settling Time (within 10% of bias)	<10 sec	<10 sec	
Spectral Noise (1 Hz)	900 µg/√Hz	8820 (µm/sec²/√Hz	[1]
Spectral Noise (10 Hz)	250 µg/√Hz	2450 (µm/sec²/√Hz	[1]
Spectral Noise (100 Hz)	100 µg/√Hz	981 (µm/sec²/√Hz	[1]
Spectral Noise (1 kHz)	50 µg/√Hz	490 (µm/sec²/√Hz	[1]
Physical			
Sensing Element	Ceramic	Ceramic	
Sensing Geometry	Shear	Shear	
Housing Material	Titanium	Titanium	
Sealing	Hermetic	Hermetic	
Size (Height x Length x Width)	0.28 in x 0.47 in x 0.47 in	7.0 mm x 12.0 mm x 12.0 mm	
Weight (without cable)	0.11 oz	3.1 gm	[1]
Electrical Connector	8-36 4-Pin	8-36 4-Pin	
Electrical Connection Position	Side	Side	
Mounting	Adhesive	Adhesive	

CE[4]



All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.
ICP® is a registered trademark of PCB group, Inc.

Optional Versions (Optional versions have identical specifications and accessories as listed for standard model except where noted below. More than one option maybe used.)

HT - High temperature, extends normal operation temperatures		
Temperature Range (Operating)	-65 to +325 °F	-54 to +163 °C
J - Ground Isolated		
Electrical Isolation (Base)	10^8 Ohm	10^8 Ohm
Size (Height x Length x Width)	0.33 in x 0.47 in x 0.47 in	8.3 mm x 12.0 mm x 12.0 mm
Weight	0.13 oz	3.7 gm

Notes

[1] Typical.
[2] 250° F to 325° F data valid with HT option only.
[3] Zero-based, least-squares, straight line method.
[4] See PCB Declaration of Conformance PS023 for details.

Supplied Accessories

034K10 Cable 10FT Mini 4 Pin To (3) BNC (1)
080A109 Petro Wax (1)
080A90 Quick Bonding Gel (1)
ACS-1T NIST traceable triaxial amplitude response, 10 Hz to upper 5% frequency. (1)

Entered: LLH	Engineer: AJA	Sales: WDC	Approved: LLH	Spec Number:
Date: 04/21/2010	Date: 04/20/2010	Date: 04/20/2010	Date: 04/22/2010	**10463**

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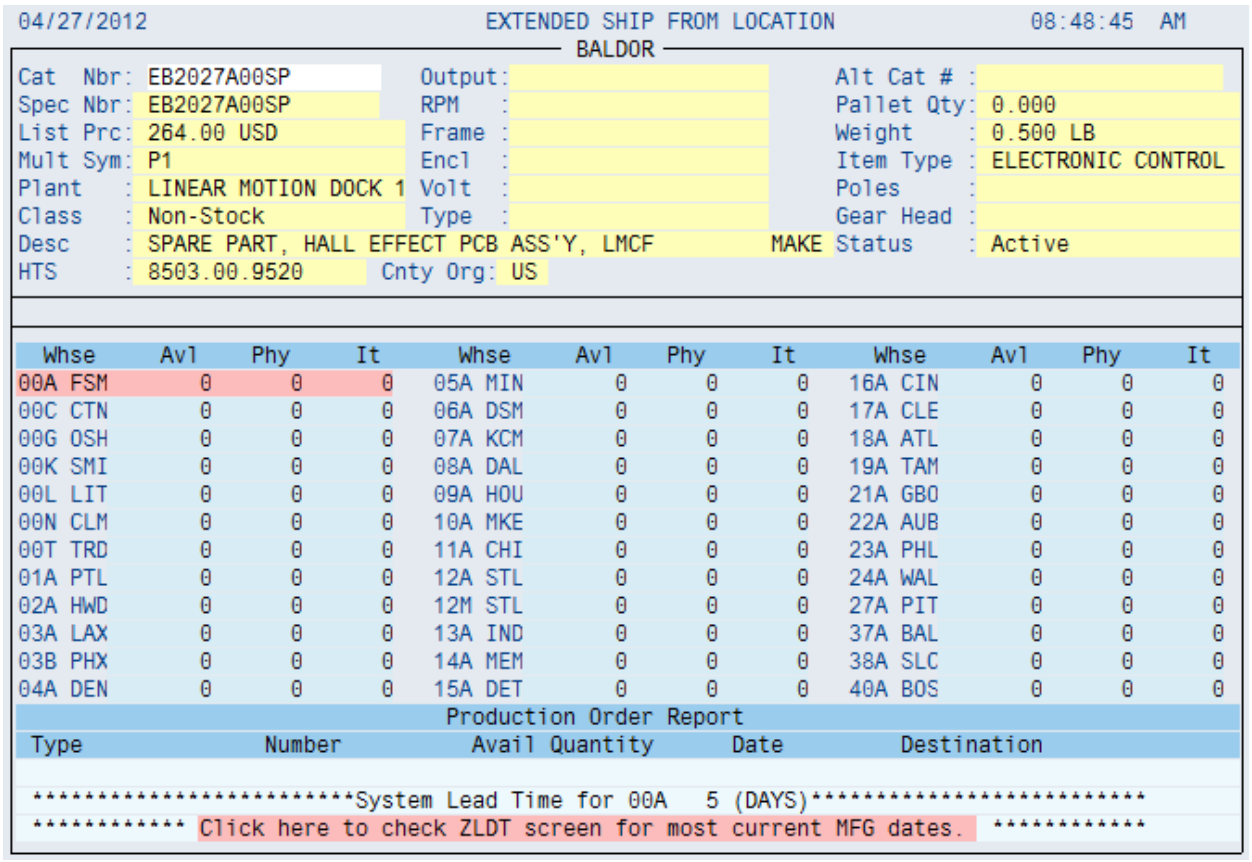
Web site: www.pcb.com

11.11 Appendix L (Hall Effect Sensor Board)

Hall-effect Sensor Board



04/27/2012 EXTENDED SHIP FROM LOCATION 08:48:45 AM

BALDOR

Cat Nbr:	EB2027A00SP	Output:		Alt Cat # :	
Spec Nbr:	EB2027A00SP	RPM :		Pallet Qty:	0.000
List Prc:	264.00 USD	Frame :		Weight :	0.500 LB
Mult Sym:	P1	Encl :		Item Type :	ELECTRONIC CONTROL
Plant :	LINEAR MOTION DOCK 1	Volt :		Poles :	
Class :	Non-Stock	Type :		Gear Head :	
Desc :	SPARE PART, HALL EFFECT PCB ASS'Y, LMCF		MAKE	Status :	Active
HTS :	8503.00.9520	Cnty Org:	US		

Whse	Avl	Phy	It	Whse	Avl	Phy	It	Whse	Avl	Phy	It
00A FSM	0	0	0	05A MIN	0	0	0	16A CIN	0	0	0
00C CTN	0	0	0	06A DSM	0	0	0	17A CLE	0	0	0
00G OSH	0	0	0	07A KCM	0	0	0	18A ATL	0	0	0
00K SMI	0	0	0	08A DAL	0	0	0	19A TAM	0	0	0
00L LIT	0	0	0	09A HOU	0	0	0	21A GBO	0	0	0
00N CLM	0	0	0	10A MKE	0	0	0	22A AUB	0	0	0
00T TRD	0	0	0	11A CHI	0	0	0	23A PHL	0	0	0
01A PTL	0	0	0	12A STL	0	0	0	24A WAL	0	0	0
02A HWD	0	0	0	12M STL	0	0	0	27A PIT	0	0	0
03A LAX	0	0	0	13A IND	0	0	0	37A BAL	0	0	0
03B PHX	0	0	0	14A MEM	0	0	0	38A SLC	0	0	0
04A DEN	0	0	0	15A DET	0	0	0	40A BOS	0	0	0

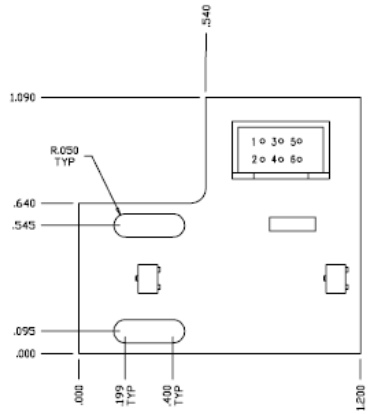
Production Order Report

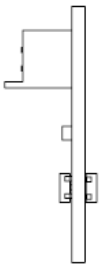
Type	Number	Avail Quantity	Date	Destination

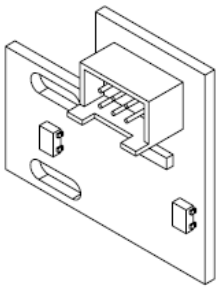
**********System Lead Time for 00A 5 (DAYS)**********

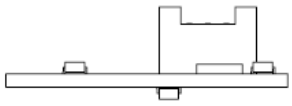
********** Click here to check ZLDT screen for most current MFG dates. **********

EB2027A00









PIN #	FUNCTION
1	C
2	B
3	N/C
4	GND
5	A
6	+5V

MASS =

TOL UNLESS SPEC.
2 PLC DEC.=±.020
3 PLC DEC.=±.005
ANG=±.5° RAD=.015
FINISH=125

EB2027A00

REV. DESC: NEW			BALDOR ELECTRIC Co.
REV. LTR: –	VERSION 00	TDR: 000000432896	
EB2027A00	FILE: \LAD\00007\238	REVISED: 11:36:45 06/06/2007	HALL EFFECT PCB ASS'Y, LMCF
	MTL: –	BY: ENBEVCO	

11.12 Appendix M (Linear Encoder Spec Sheet)

1 General Description

The AS5304/AS5306 are single-chip IC's with integrated Hall elements for measuring linear or rotary motion using multi-pole magnetic strips or rings.

This allows the usage of the AS5304/AS5306 in applications where the Sensor IC cannot be mounted at the end of a rotating device (e.g. at hollow shafts). Instead, the AS5304/AS5306 are mounted off-axis underneath a multi-pole magnetized ring or strip and provides a quadrature incremental output with 40 pulses per pole period at speeds of up to 20 meters/sec (AS5304) or 12 meters/sec (AS5306).

A single index pulse is generated once for every pole pair at the Index output.

Using, for example, a 32pole-pair magnetic ring, the AS5304/AS5306 can provide a resolution of 1280 pulses/rev, which is equivalent to 5120 positions/rev or 12.3bit. The maximum speed at this configuration is 9375 rpm.

The pole pair length is 4mm (2mm north pole / 2mm south pole) for the AS5304, and 2.4mm (1.2mm north pole / 1.2mm south pole) for the AS5306. The chip accepts a magnetic field strength down to 5mT (peak).

Both chips are available with **push-pull outputs (AS530xA)** or with **open drain outputs (AS530xB)**.

The AS5304/AS5306 are available in a small 20-pin TSSOP package and specified for an operating ambient temperature of -40° to +125°C.

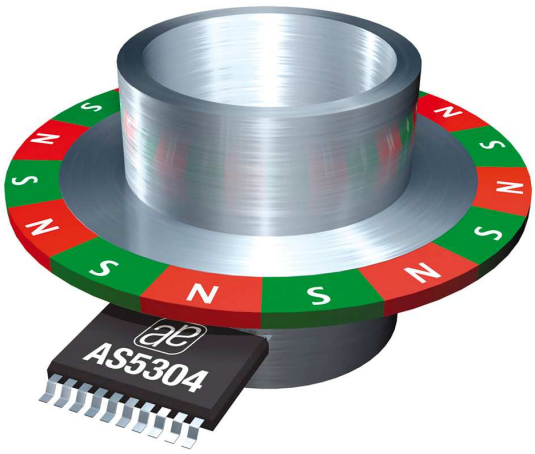


Figure 1: AS5304 (AS5306) with multi-pole ring magnet.

2 Benefits

- Complete system-on-chip
- High reliability due to non-contact sensing
- Suitable for the use in harsh environments
- Robust against external magnetic stray fields

3 Key Features

- High speed, up to 20m/s (AS5304)
  12m/s (AS5306)
- Magnetic pole pair length: **4mm (AS5304)** or
  2.4mm (AS5306)
- Resolution: **25µm (AS5304)** or **15µm (AS5306)**
- 40 pulses / 160 positions per magnetic period.
- 1 index pulse per pole pair
- Linear movement measurement using multi-pole magnetic strips
- Circular off-axis movement measurement using multi-pole magnetic rings
- 4.5 to 5.5V operating voltage
- Magnetic field strength indicator, magnetic field alarm for end-of-strip or missing magnet

4 Applications

The AS5304/AS5306 are ideal for high speed linear motion and off-axis rotation measurement in applications such as

- electrical motors
- X-Y-stages
- rotation knobs
- industrial drives

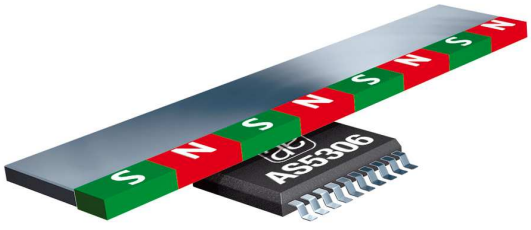


Figure 2: AS5306 (AS5304) with magnetic multi-pole strip magnet for linear motion measurement

5 Functional Description

The AS5304/AS5306 require a multi-pole magnetic strip or ring with a pole length of 2mm (4mm pole pair length) on the AS5304, and a pole length of 1.2mm (2.4mm pole pair length) on the AS5306. The magnetic field strength of the multi-pole magnet should be in the range of 5 to 60mT at the chip surface.

The Hall elements on the AS5304/AS5306 are arranged in a linear array.

By moving the multi-pole magnet over the Hall array, a sinusoidal signal (SIN) is generated internally. With proper configuration of the Hall elements, a second 90° phase shifted sinusoidal signal (COS) is obtained. Using an interpolation circuit, the length of a pole pair is divided into 160 positions and further decoded into 40 quadrature pulses.

An Automatic Gain Control provides a large dynamic input range of the magnetic field.

An Analog output pin (AO) provides an analog voltage that changes with the strength of the magnetic field (see chapter 8).

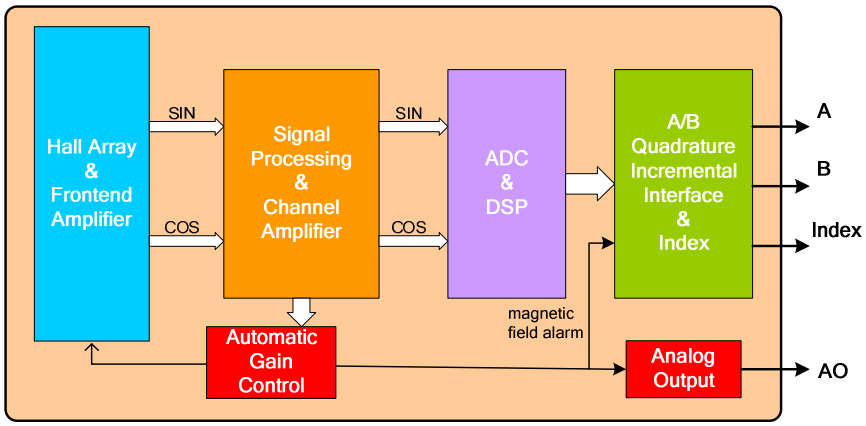


Figure 3: AS5304 / AS5306 block diagram

6 Sensor Placement in Package

TSSOP20 / 0.65mm pin pitch

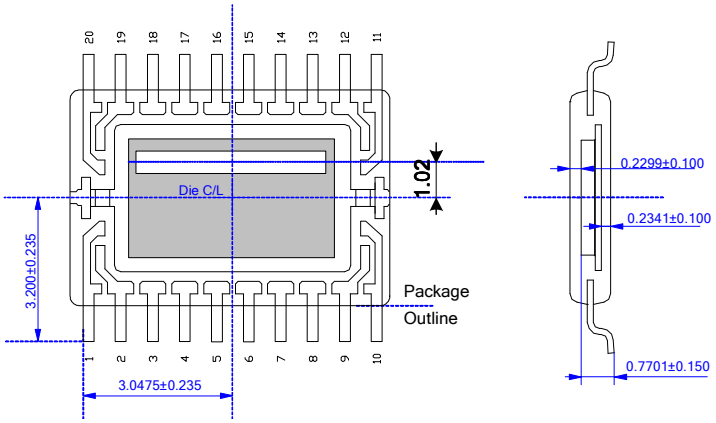


Figure 4: Sensor in package

Die Tilt Tolerance ±1°

6.1 Pin Description

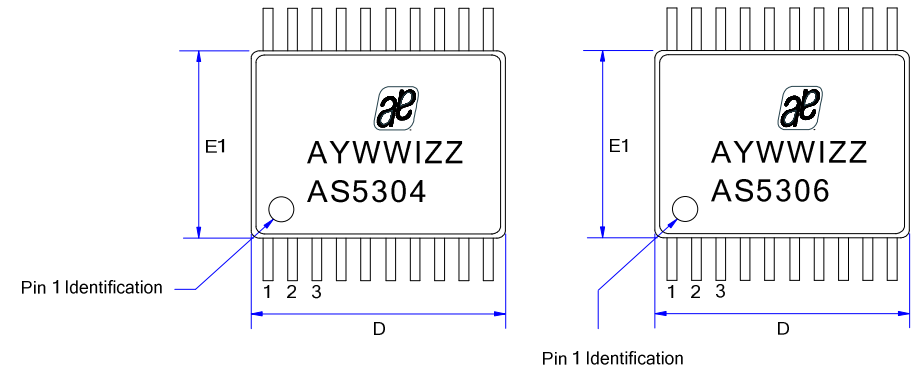
Pin	Pin Name	Pin Type	Notes
1	VSS	S	Supply ground
2	A	DO_OD	Incremental quadrature position output A. Short circuit current limitation
3	VDDP	S	Peripheral supply pin, connect to VDD
4	B	DO_OD	Incremental quadrature position output B. Short Circuit Current Limitation
5,12,13, 14,17,18,19	TEST	AIO	test pins, must be left open
6	AO	AO	AGC Analogue Output. (Used to detect low magnetic field strength)
7	VDD	S	Positive supply pin
8	Index	DO_OD	Index output, active HIGH. Short Circuit Current Limitation
9,10,11	TEST	AIO	test pins, must be left open
15	TEST_GND	S	test pin, must be connected to VSS
16	VDDA Hall	S	Hall Bias Supply Support (connected to VDD)
20	ZPZmskdis	DI	Test input, connect to VSS during operation

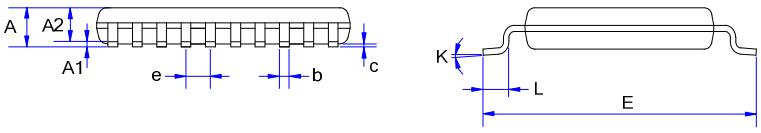
PIN Types:

S	supply pin	AO	analogue output
AIO	analog input / output	DI	digital input
DO_OD	digital output push pull or open drain (programmable)		

6.2 Package Drawings and Markings

20 Lead Thin Shrink Small Outline Package – **TSSOP20**





Dimensions						
Symbol	mm			inch		
	Min	Typ	Max	Min	Typ	Max
A	-	-	1.20	-	-	0.047
A1	0.05	-	0.15	0.002	-	0.006
A2	0.80	1.00	1.05	0.031	0.039	0.041
b	0.19	-	0.30	0.007	-	0.012
c	0.09	-	0.20	0.004	-	0.008
D	6.40	6.50	6.60	0.252	0.256	0.260
E		6.40			0.252	
E1	4.30	4.40	4.50	0.169	0.173	0.177
e		0.65			0.0256	
K	0°	-	8°	0°	-	8°
L	0.45	0.60	0.75	0.018	0.024	0.030

Marking: AYWWIZZ

A: Pb-Free Identifier
Y: Last Digit of Manufacturing Year
WW: Manufacturing Week
I: Plant Identifier
ZZ: Traceability Code

JEDEC Package Outline Standard:
MO-153-AC

Thermal Resistance $R_{th(j-a)}$:
89 K/W in still air, soldered on PCB.

IC's marked with a white dot or the letters "ES" denote Engineering Samples

6.3 Electrical Connection

The supply pins VDD, VDDP and VDDA are connected to +5V. Pins VSS and TEST_GND are connected to the supply ground. A 100nF decoupling capacitor close to the device is recommended.

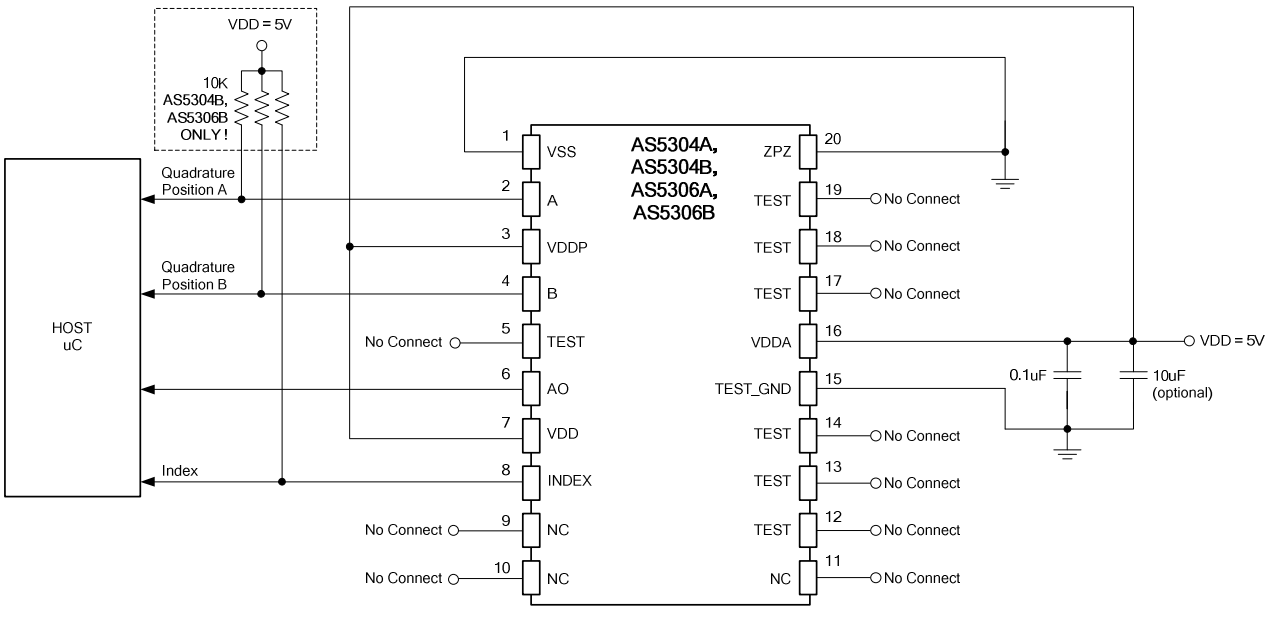


Figure 5: Electrical connection of the AS5304/AS5306

7 Incremental Quadrature AB Output

The digital output is compatible to optical incremental encoder outputs. Direction of rotation is encoded into two signals A and B that are phase-shifted by 90°. Depending on the direction of rotation, A leads B (CW) or B leads A (CCW).

7.1.1 Index Pulse

A single index pulse is generated once for every pole pair. One pole pair is interpolated to 40 quadrature pulses (160 steps), so one index pulse is generated after every 40 quadrature pulses (see Figure 6)

The Index output is switched to Index = high, when a magnet is placed over the Hall array as shown in Figure 7, top graph: the north pole of the magnet is placed over the left side of the IC (top view, pin#1 at bottom left) and the south pole is placed over the right side of the IC.

The index output will switch back to Index = low, when the magnet is moved by one LSB from position X=0 to X=X1, as shown in Figure 7, bottom graph. One LSB is 25µm for AS5304 and 15µm for AS5306.

Note: Since the small step size of 1 LSB is hardly recognizable in a correctly scaled graph it is shown as an exaggerated step in the bottom graph of Figure 7.

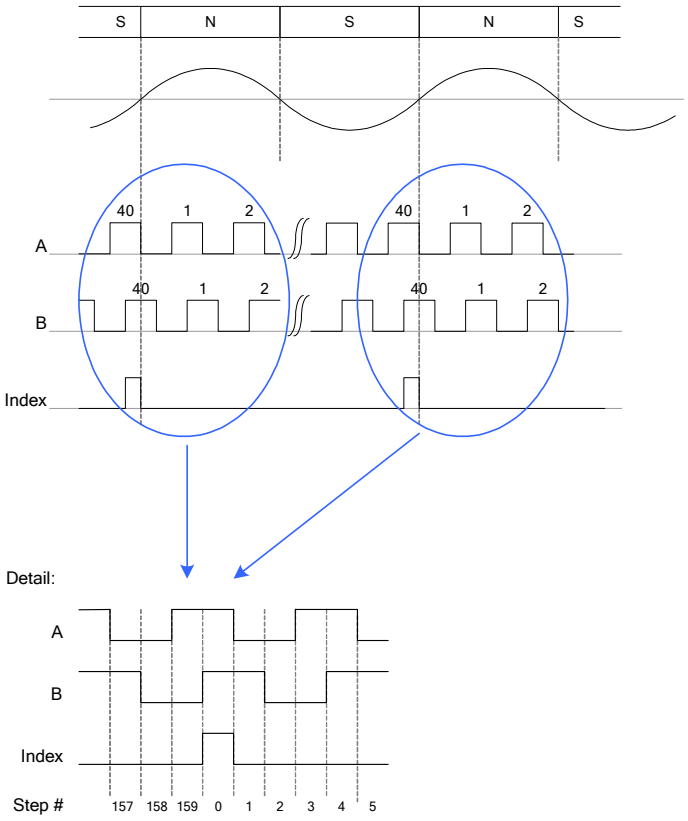


Figure 6: Quadrature A / B and Index output

7.1.2 Magnetic Field Warning Indicator

The AS5304 can also provide a low magnetic field warning to indicate a missing magnet or when the end of the magnetic strip has been reached. This condition is indicated by using a combination of A, B and Index, that does not occur in normal operation:

A low magnetic field is indicated with:

Index = high
A=B=low

7.1.3 Vertical Distance between Magnet and IC

The recommended vertical distance between magnet and IC depends on the strength of the magnet and the length of the magnetic pole.

Typically, the vertical distance between magnet and chip surface should not exceed ½ of the pole length.

That means for AS5304, having a pole length of 2.0mm, the maximum vertical gap should be 1.0mm,

For the AS5306, having a pole length of 1.2mm, the maximum vertical gap should be 0.6mm

These figures refer to the chip surface. Given a typical distance of 0.2mm between chip surface and IC package surface, the recommended vertical distances between **magnet and IC surface** are therefore:

AS 5304: ≤ 0.8mm

AS 5306: ≤ 0.4mm

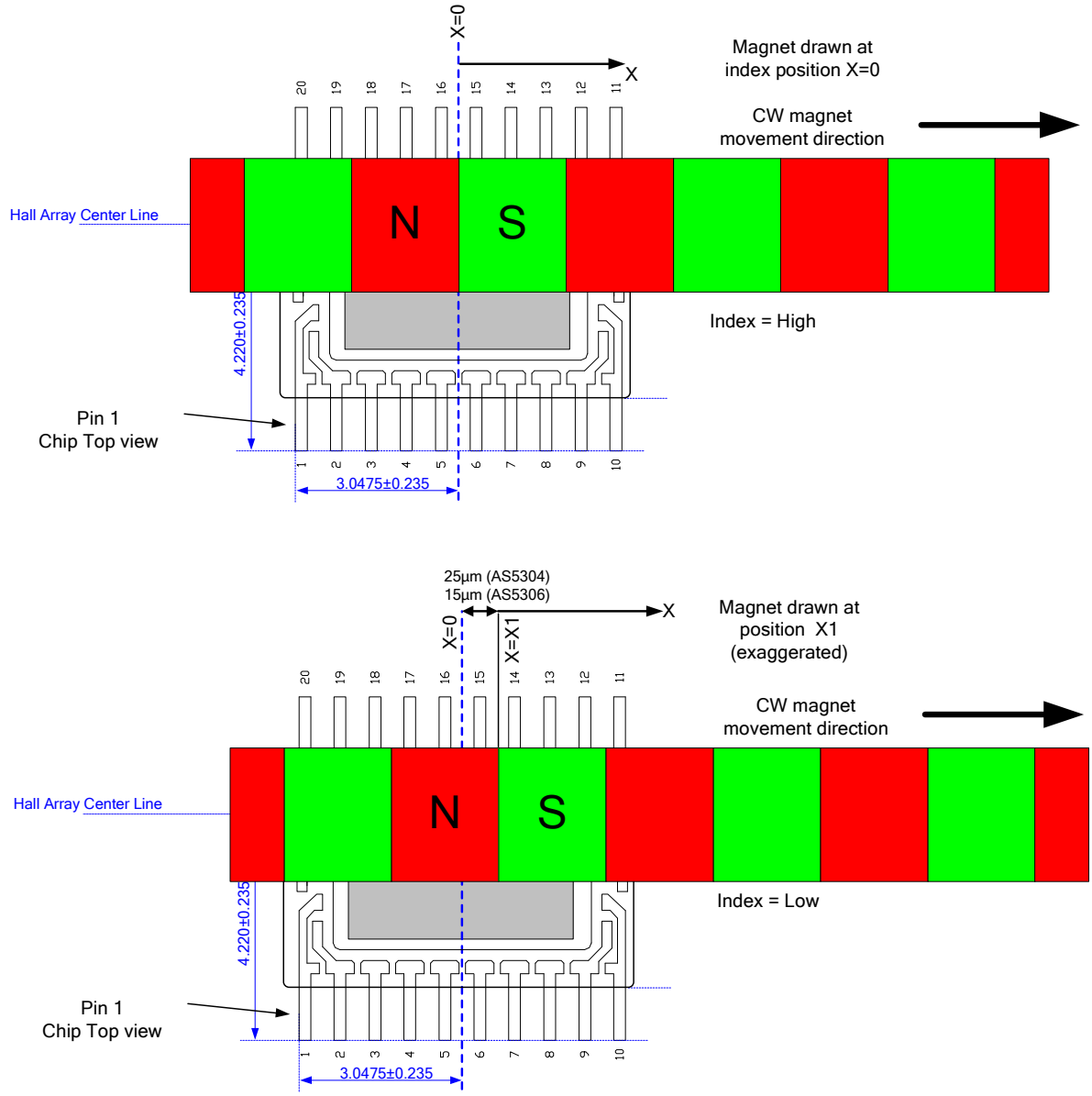


Figure 7: Magnet placement for index pulse generation

7.1.4 Soft Stop Feature for Linear Movement Measurement

When using long multi-pole strips, it may often be necessary to start from a defined home (or zero) position and obtain absolute position information by counting the steps from the defined home position. The AS5304/AS5306 provide a soft stop feature that eliminates the need for a separate electro-mechanical home position switch or an optical light barrier switch to indicate the home position.

The magnetic field warning indicator (see 7.1.2) together with the index pulse can be used to indicate a unique home position on a magnetic strip:

1. First the AS5304/AS5306 move to the end of the strip, until a magnetic field warning is displayed (Index = high, A=B=low)
2. Then, the AS5304/AS5306 move back towards the strip until the first index position is reached (note: an index position is generated once for every pole pair, it is indicated with: Index = high, A=B= high). Depending on the polarity of the strip magnet, the first index position may be generated when the end of the magnet strip only covers one half of the Hall array. This position is not recommended as a defined home position, as the accuracy of the AS5304/AS5306 are reduced as long as the multi-pole strip does not fully cover the Hall array.

3. It is therefore recommended to continue to the next (second) index position from the end of the strip (Index = high, A=B= high). This position can now be used as a defined home position.

7.2 Incremental Hysteresis

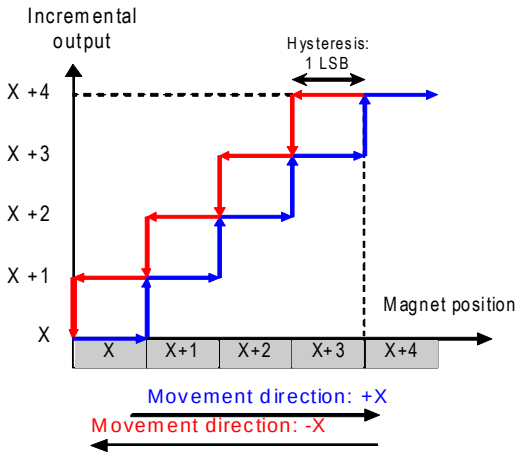


Figure 8: Hysteresis of the incremental output

If the magnet is sitting right at the transition point between two steps, the noise in the system may cause the incremental outputs to jitter back and forth between these two steps, especially when the magnetic field is weak.

To avoid this unwanted jitter, a hysteresis has been implemented. The hysteresis lies between 1 and 2 LSB, depending on device scattering. Figure 8 shows an example of 1LSB hysteresis: the horizontal axis is the lateral position of the magnet as it scans across the IC, the vertical axis is the change of the incremental outputs, as they step forward (blue line) with movement in +X direction and backward (red line) in –X direction.

Note: 1LSB = 25µm for AS5304, 15µm for AS5306

7.3 Integral Non-Linearity (INL)

The INL (integral non-linearity) is the deviation between indicated position and actual position. It is better than 1LSB for both AS5304 and AS5306, assuming an ideal magnet. Pole length variations and imperfections of the magnet material, which lead to a non-sinusoidal magnetic field will attribute to additional linearity errors.

7.3.1 Error Caused by Pole Length Variations

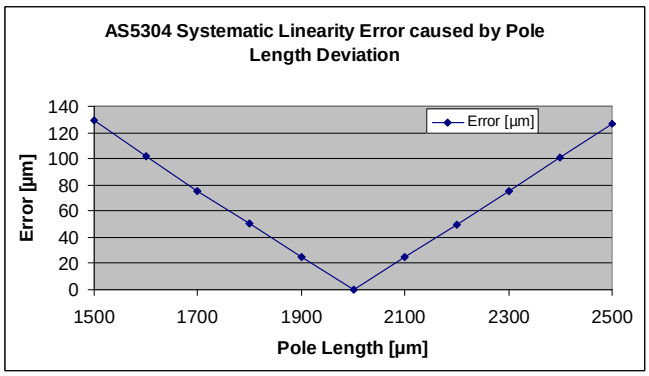


Figure 9: Additional error caused by pole length variation: AS5304

Figure 9 and Figure 10 show the error caused by a non-ideal pole length of the multi-pole strip or ring.

This is less of an issue with strip magnets, as they can be manufactured exactly to specification using the proper magnetization tooling.

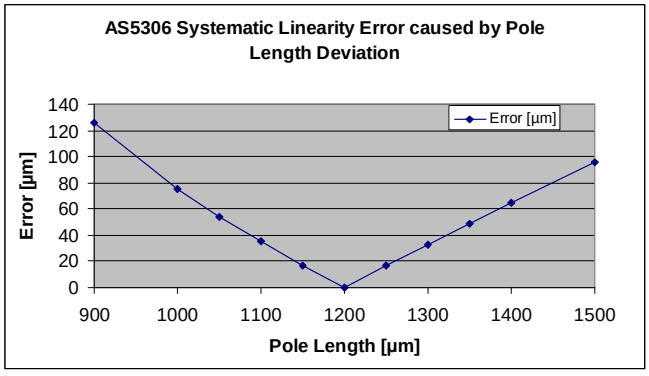


Figure 10: Additional error caused by pole length variation: AS5306

However, when using a ring magnet (see Figure 1) the pole length differs depending on the measurement radius. For optimum performance it is therefore essential to mount the IC such that the Hall sensors are exactly underneath the magnet at the radius where the pole length is 2.0mm (AS5304) or 1.2mm (AS5306), see also 8.1.2.

Note that this is an additional error, which must be added to the intrinsic errors INL (see 7.3) and DNL (see 7.4).

7.4 Dynamic Non-Linearity (DNL)

The DNL (dynamic non-linearity) describes the non-linearity of the incremental outputs from one step to the next. In an ideal system, every change of the incremental outputs would occur after exactly one LSB (e.g. 25µm on AS5304). In practice however, this step size is not ideal, the output state will change after 1LSB +/-DNL. The DNL must be <+/- ½ LSB to avoid a missing code. Consequently, the incremental outputs will change when the magnet movement over the IC is minimum 0.5 LSB and maximum 1.5 LSB's.

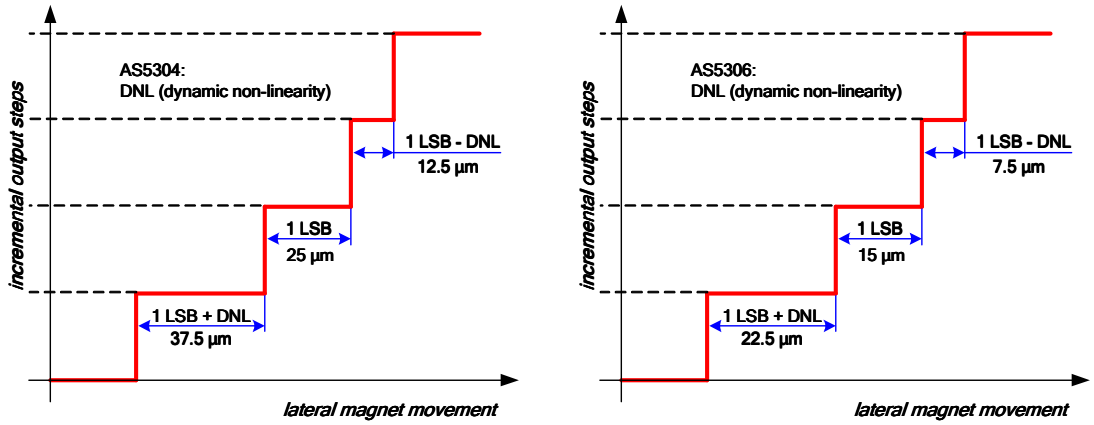


Figure 11: DNL of AS5304 (left) and AS5306 (right)

8 The AO Output

The Analog Output (AO) provides an analog output voltage that represents the Automatic Gain Control (AGC) of the Hall sensors signal control loop.

This voltage can be used to monitor the magnetic field strength and hence the gap between magnet and chip surface:

- Short distance between magnet and IC → strong magnetic field → low loop gain → low AO voltage
- Long distance between magnet and IC → weak magnetic field → high loop gain → high AO voltage

For ideal operation, the AO voltage should be between 1.0 and 4.0V (typical; see 9.5).

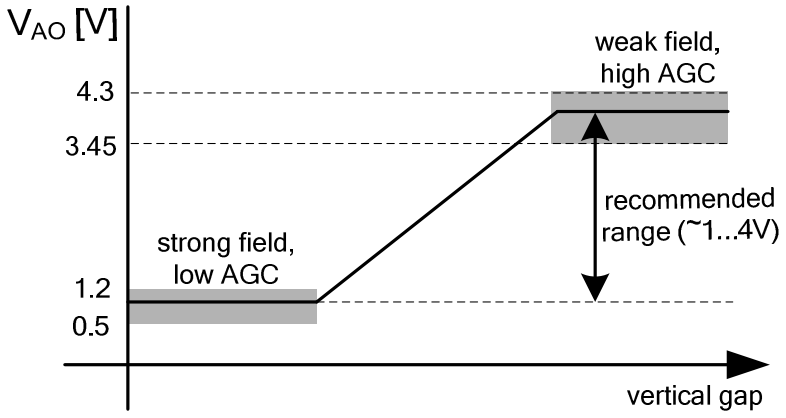


Figure 12: AO output versus AGC, magnetic field strength, magnet-to-IC gap

8.1 Resolution and Maximum Rotating Speed

When using the AS5304/AS5306 in an off-axis rotary application, a multi-pole ring magnet must be used. Resolution, diameter and maximum speed depend on the number of pole pairs on the ring.

8.1.1 Resolution

The angular resolution increases linearly with the number of pole pairs. One pole pair has a resolution (= interpolation factor) of 160 steps or 40 quadrature pulses.

Resolution [steps] = ***[interpolation factor] x [number of pole pairs]***

Resolution [bit] = ***log (resolution[steps]) / log (2)***

Example: multi-pole ring with 22 pole pairs

Resolution = 160x22 = 3520 steps per revolution

= 40x22 = 880 quadrature pulses / revolution

= 11.78 bits per revolution = 0.1023° per step

8.1.2 Multi-pole Ring Diameter

The length of a pole pair across the median of the multi-pole ring must remain fixed at either 4mm (AS5304) or 2.4mm (AS5306). Hence, with increasing pole pair count, the diameter increases linearly with the number of pole pairs on the magnetic ring.

Magnetic ring diameter = ***[pole length] * [number of pole pairs] / π***

for AS5304: d = 4.0mm * number of pole pairs / π

for AS5306: d = 2.4mm * number of pole pairs / π

Example: same as above: multi-pole ring with 22 pole pairs for AS5304

Ring diameter = 4 * 22 / 3.14 = 28.01mm (this number represents the median diameter of the ring, this is where the Hall elements of the AS5304/AS5306 should be placed; see Figure 4)

For the AS5306, the same ring would have a diameter of: 2.4 * 22 / 3.14 = 16.8mm

8.1.3 Maximum Rotation Speed

The AS5304/AS5306 use a fast interpolation technique allowing an input frequency of 5kHz. This means, it can process magnetic field changes in the order of 5000 pole pairs per second or 300,000 revolutions per minute. However, since a magnetic ring consists of more than one pole pair, the above figure must be divided by the number of pole pairs to get the maximum rotation speed:

Maximum rotation speed = ***300,000 rpm / [number of pole pairs]***

Example: same as above: multi-pole ring with 22 pole pairs:

Max. speed = 300,000 / 22 = 13,636 rpm (this is independent of the pole length)

8.1.4 Maximum Linear Travelling Speed

For linear motion sensing, a multi-pole strip using equally spaced north and south poles is used. The pole length is again fixed at 2.0mm for the AS5304 and 1.2mm for the AS5306. As shown in 8.1.3 above, the sensors can process up to 5000 pole pairs per second, so the maximum travelling speed is:

Maximum linear travelling speed = ***5000 * [pole pair length]***

Example: linear multi-pole strip:

Max. linear travelling speed = 4mm * 5000 1/sec = 20,000mm/sec = 20m/sec for AS5304

Max. linear travelling speed = 2.4mm * 5000 1/sec = 12,000mm/sec = 12m/sec for AS5306

9 GENERAL DEVICE SPECIFICATIONS

9.1 Absolute Maximum Ratings (Non Operating)

Stresses beyond those listed under “Absolute Maximum Ratings“ may cause permanent damage to the device.

Parameter	Symbol	Min	Max	Unit	Note
Supply	VDD	-0.3	7	V	
Input pin voltage	V_{in}	VSS-0.5	VDD+0.5	V	
Input current (latchup immunity)	I_{scr}	-100	100	mA	Norm: JESD78
ESD		+/-2		kV	Norm: MIL 883 E method 3015
Package thermal resistance	Θ_{JA}		114.5	°C /W	Still Air / Single Layer PCB
Storage temperature	T_{strg}	-55	150	°C	
Soldering conditions	T_{body}		260	°C	Norm: IPC/JEDEC J-STD-020C
Humidity non-condensing		5	85	%	

9.2 Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit	Note
Positive supply voltage	AVDD	4.5	5.0	5.5	V	
Digital supply voltage	DVDD					
Negative supply voltage	VSS	0.0	0.0	0.0	V	
Power supply current, AS5304	IDD	25		35	mA	A/B/Index, AO unloaded!
Power supply current, AS5306		20		30		
Ambient temperature	T_{amb}	-40		125	°C	
Junction temperature	T_J	-40		150	°C	
Resolution	LSB		25		µm	AS5304
			15			AS5306
Integral nonlinearity	INL			1	LSB	Ideal input signal (ErrMax - ErrMin) / 2
Differential nonlinearity	DNL			±0.5	LSB	No missing pulses. optimum alignment
Hysteresis	Hyst	1	1.5	2	LSB	

9.3 System Parameters

Parameter	Symbol	Min	Max	Unit	Note
Power up time	T_{PwrUp}		500	µs	Amplitude within valid range / Interpolator locked, A B Index enabled
Propagation delay	T_{Prop}		20	µs	Time between change of input signal to output signal

9.4 A / B / C Push/Pull or Open Drain Output

Push Pull Mode is set for AS530xA, Open Drain Mode is set for AS530xB versions.

Parameter	Symbol	Min	Typ	Max	Unit	Note
High level output voltage	V_{OH}	0.8 VDD			V	Push/Pull mode
Low level output voltage	V_{OL}			0.4 + VSS	V	
Current source capability	I_{LOH}	12	14		mA	Push/Pull mode
Current sink capability	I_{LOL}	13	15		mA	
Short circuit limitation current	I_{Short}		25	39	mA	Reduces maximum operating temperature
Capacitive load	C_L		20		pF	See Figure 13
Load resistance	R_L		820		Ω	See Figure 13
Rise time	t_R			1.2	µs	Push/Pull mode
Fall time	t_F			1.2	µs	

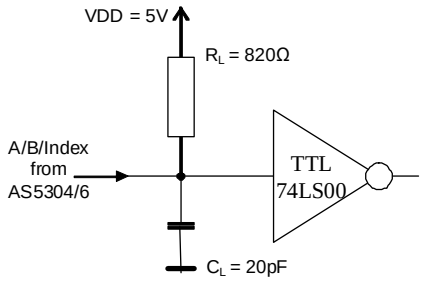


Figure 13: Typical digital load

9.5 CAO Analogue Output Buffer

Parameter	Symbol	Min	Typ	Max	Unit	Note
Minimum output voltage	$V_{OutRange}$	0.5	1	1.2	V	Strong field, min. AGC
Maximum output voltage	$V_{OutRange}$	3.45	4	4.3	V	Weak field, max. AGC
Offset	V_{Offs}			±10	mV	
Current sink / source capability	I_L	5			mA	
Average short circuit current	I_{Short}	6		40	mA	Reduces maximum Operating Temperature
Capacitive load	C_L		10		pF	
Bandwidth	BW		5		KHz	

9.6 Magnetic Input

Parameter	Symbol	Min	Typ	Max	Unit	Note
Magnetic pole length	L_{P_FP}		2.0		mm	AS5304
			1.2			AS5306
Magnetic pole pair length	T_{FP}		4.0		mm	AS5304
			2.4			AS5306
Magnetic amplitude	A_{mag}	5		60	mT	
Operating dynamic input range		1:12		1:24		
Magnetic offset	Off_{mag}			±0.5	mT	
Magnetic temperature drift	T_{dmag}			-0.2	%/K	
Input frequency	f_{mag}	0		5	kHz	

Table 1: AS5304 ordering guide

Device	Resolution	Magnet Pole Length	Digital Outputs
AS5304A	25µm	2mm	Push Pull
AS5304B	25µm	2mm	Open Drain

Table 2: AS5306 ordering guide

Device	Resolution	Magnet Pole Length	Digital Outputs
AS5306A	15µm	1.2mm	Push Pull
AS5306B	15µm	1.2mm	Open Drain

Contact

Headquarters

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www.austriamicrosystems.com

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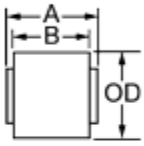
11.13 Appendix N (Thomson Rods and Linear Bearings)

Thompson Rods And Vibration damping Sleeve Bushings

Vibration-Damping Bronze Sleeve Bearings



With a flexible layer of neoprene rubber sandwiched between a protective steel shell and an SAE 841 bronze insert, these bearings quiet down equipment by absorbing vibration. The neoprene rubber also allows these bearings to accommodate shaft misalignment and adds resistance to shock loads (suddenly applied loads). The bronze insert, which is impregnated with 20% SAE 30 oil, makes them great for hard-to-lubricate areas.

View tolerance information for these bearings.

Bearing Material	Temperature Range	P max	V max	PV max
SAE 841	0° to 225° F	2,000	1,200	50,000

For Shaft Dia.	OD	Lg. (A)	Lg. (B)		Each
3/8"	1"	1"	7/8"	6364K31	$9.22
1/2"	1"	1"	7/8"	6364K32	7.77
5/8"	1 1/4"	1 1/4"	1 1/8"	6364K33	11.41
3/4"	1 1/4"	1 1/4"	1 1/8"	6364K34	10.22
1"	1 5/8"	1 1/2"	1 3/8"	6364K36	16.12

Hardened Shafts

Shaft Dia.	Dia. Tolerance
1/8"-3/16"	–0.0002" to –0.0005"
1/4"-1 1/4", 1 3/4"	–0.0005" to –0.001"
1 1/2"	–0.0006" to –0.0011"
2"	–0.0006" to –0.0013"

Shaft Dia.	Dia. Tolerance
3 mm	–0.002 to –0.008 mm
4-6 mm	0.000 to –0.008 mm
8-10 mm	0.000 to –0.009 mm
12, 15, 16 mm	0.000 to –0.011 mm
13 mm	–0.006 to –0.017 mm
20-30 mm	0.000 to –0.013 mm
35-50 mm	0.000 to –0.016 mm

Shafts are case hardened and precision ground for exacting diameter and straightness tolerances. They have a 9 rms micron finish (unless noted) for inch sizes; 12 rms micron finish (unless noted) for metric sizes. Straightness tolerance is 0.002" per foot for inch sizes; 0.03 mm per 300 mm (unless noted) for metric sizes. Ends are beveled.

See our selection of shaft supports.

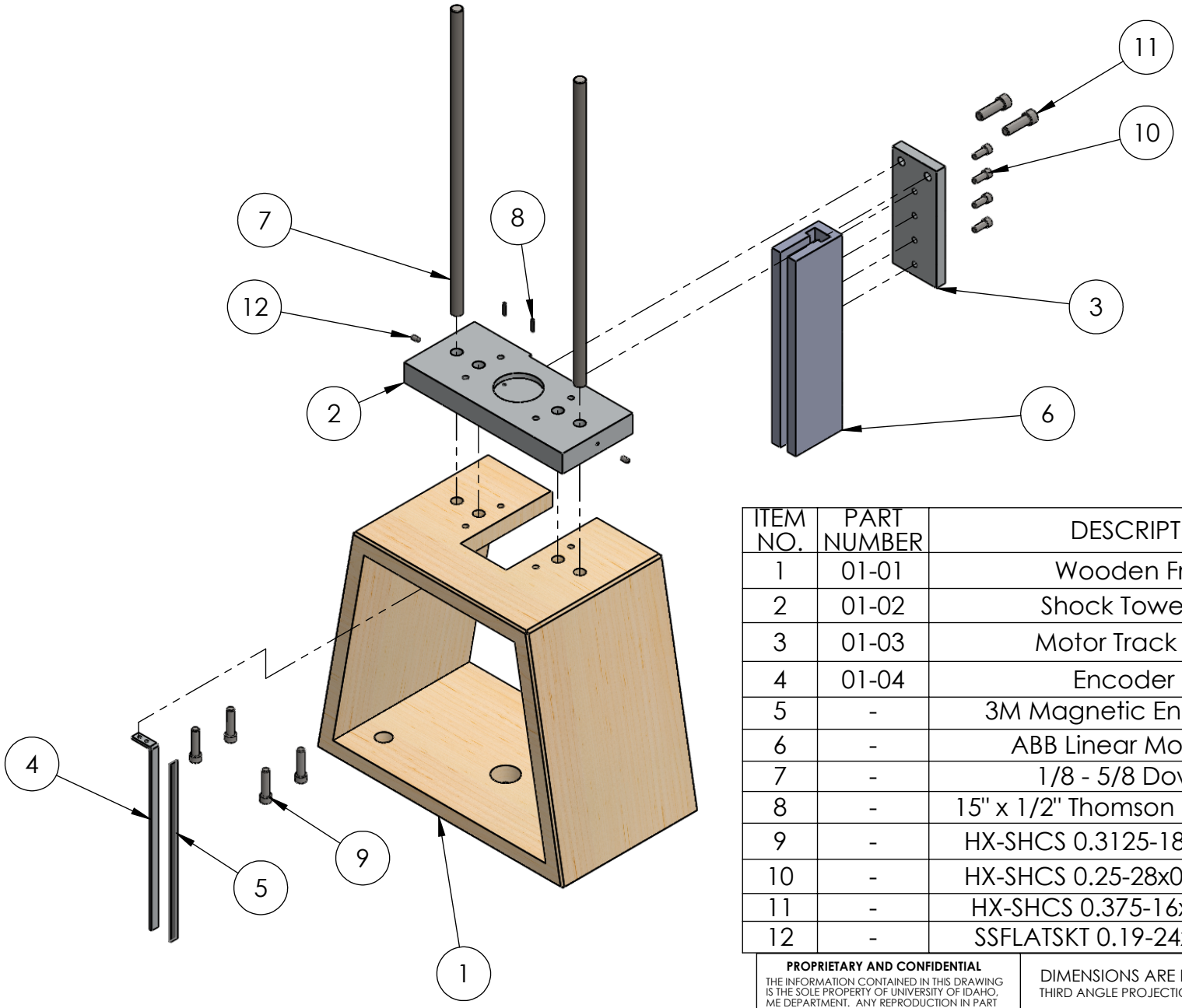
View minimum hardness depth for these shafts.

Inch Sizes—Steel

Shafts are 1566 steel; they're stronger than stainless steel shafts but are less corrosion resistant. Case hardness is Rockwell C60.

Lg.		Each
1/2" Dia.		
3"	6061K426	$3.94
4"	6061K427	4.15
5"	6061K428	4.19
6"	6061K13	4.36
7"	6061K429	4.39
8"	6061K103	4.40
9"	6061K23	4.67
10"	6061K109	5.36
12"	6061K33	6.98
14"	6061K431	7.56
15"	6061K335	8.09
16"	6061K432	8.63
18"	6061K43	9.53
20"	6061K433	11.59
24"	6061K53	12.97
30"	6061K79	15.57
36"	6061K63	19.01
42"	6061K636	22.07
48"	6061K73	24.01
60"	6061K83	30.01
72"	6061K93	38.14
84"	6061K213	42.99
96"	6061K314	51.87

11.14 Appendix M (Drawing Package)



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	SHEET
1	01-01	Wooden Frame	1	2
2	01-02	Shock Tower Base	1	3
3	01-03	Motor Track Mount	1	4
4	01-04	Encoder Rail	1	5
5	-	3M Magnetic Encoder Strip	1	-
6	-	ABB Linear Motor Track	1	-
7	-	1/8 - 5/8 Dowel Pin	2	-
8	-	15" x 1/2" Thomson Precision Rod	2	-
9	-	HX-SHCS 0.3125-18x1.25x1.25-N	4	-
10	-	HX-SHCS 0.25-28x0.625x0.625-N	4	-
11	-	HX-SHCS 0.375-16x1.25x1.25-N	2	-
12	-	SSFLATSKT 0.19-24x0.375-HX-N	2	-

Notes: 1) Cover frame with Plexi-glass for safety.
2) ABB Linear Motor 9.6 inch Track Part No. LTCF-D09.

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Various

DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Base Assembly
CHECKED BY: Nicholai Olson DATE: 5/10/2012
DRAWN BY: Cameron Hjeltness DATE: 5/10/2012
FILE NAME: 01-00 Base Assembly.SLDPRT

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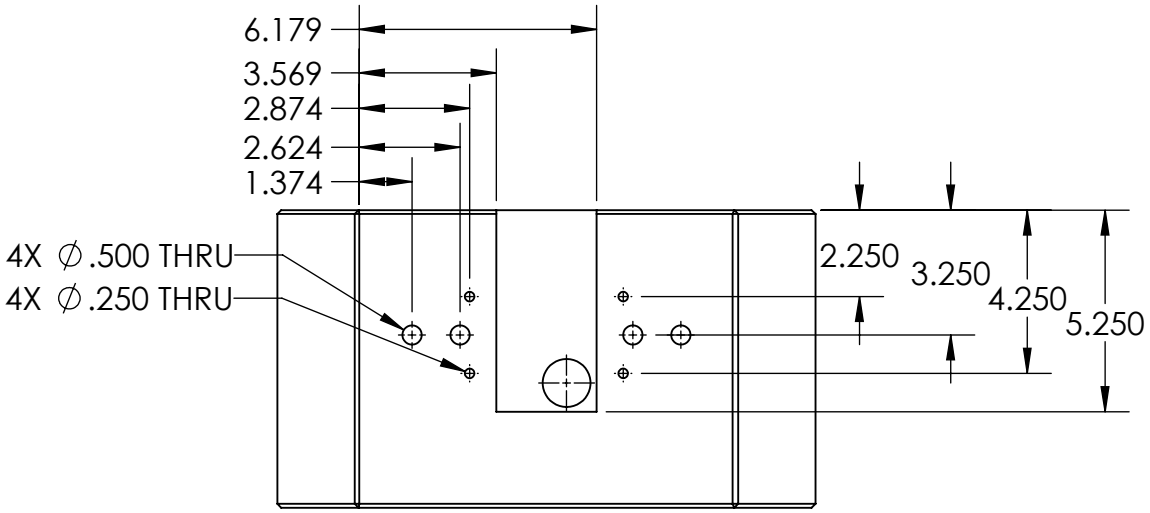
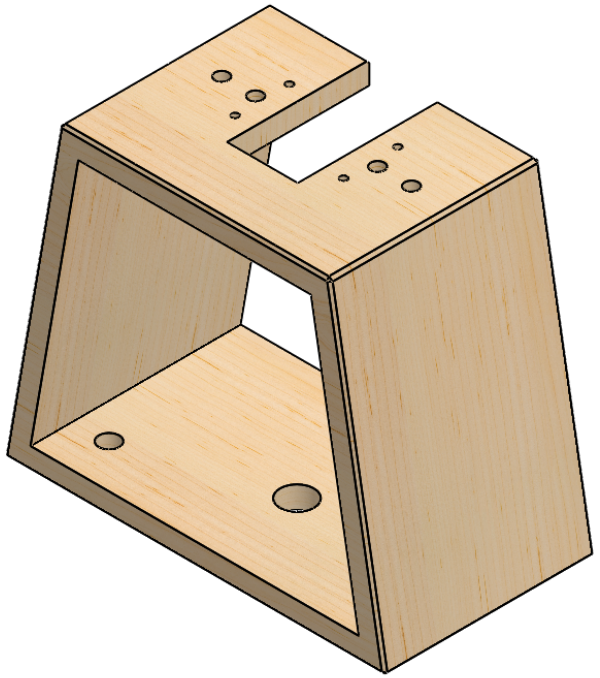
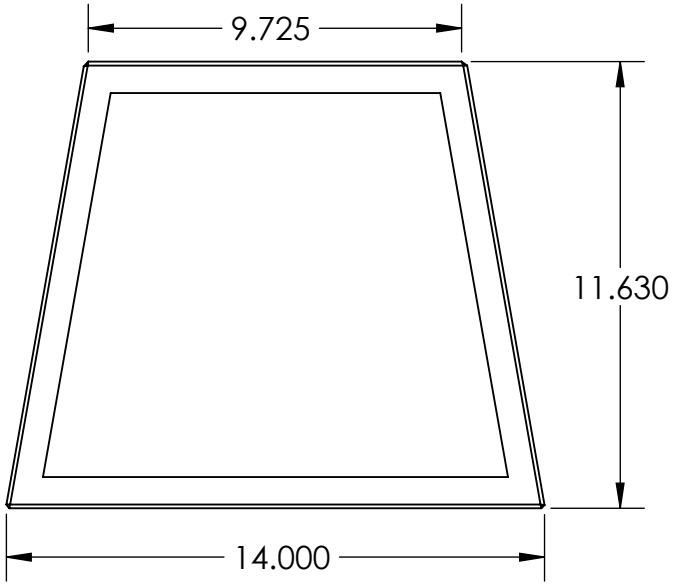
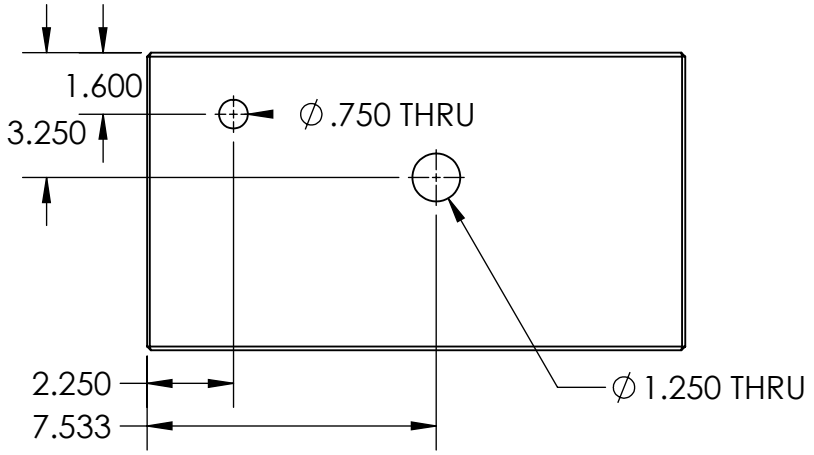
PART #: 01-00 QTY: 1
SCALE: 1:5 SHEET: 1 OF 5









Note: Construct Base from Hickory Stock 0.875 inches thick.

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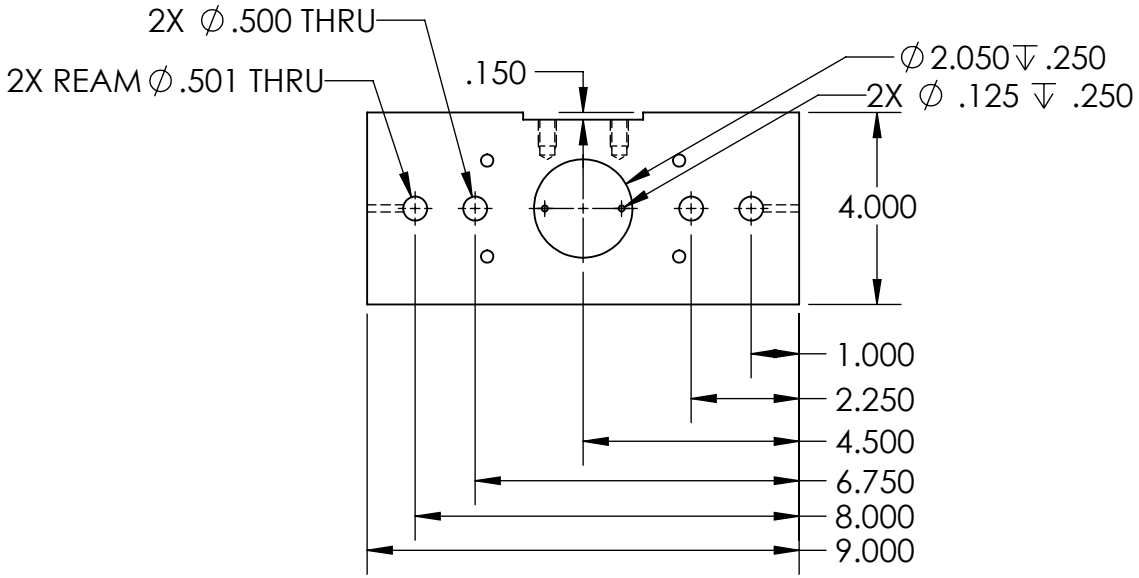
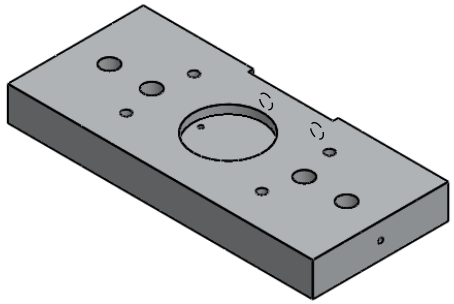
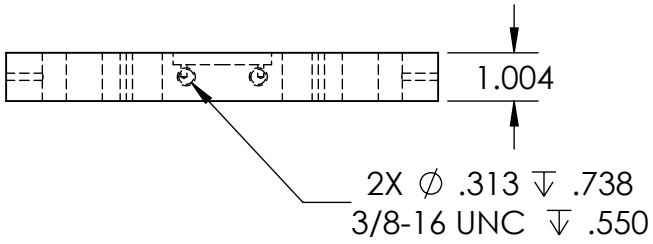
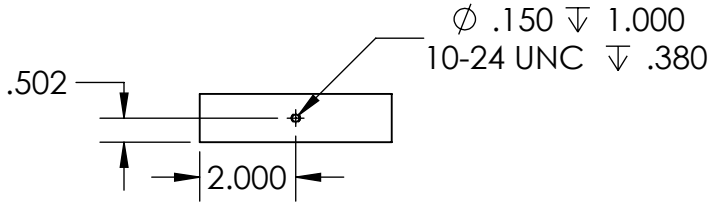
	MATERIAL: Hickory	
DEFAULT TOLERANCES: LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002 ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'	DESCRIPTION: Wooden Frame	**UNIVERSITY OF IDAHO ME DEPARTMENT**
	CHECKED BY: Nicholai Olson DATE: 5/11/2012	
	DRAWN BY: Cameron Hjeltness DATE: 5/10/2012	PART #: 01-01 QTY: 1
	FILE NAME: 01-01 Wooden Frame.SLDPRT	SCALE: 1:5 SHEET: 2 OF 5









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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061-T6 (SS)

DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Shock Tower Base
CHECKED BY: Nicholai Olson DATE: 5/10/2012
DRAWN BY: Travis Nebeker DATE: 5/10/2012
FILE NAME: 01-02 Shock Tower Base.SLDPRT

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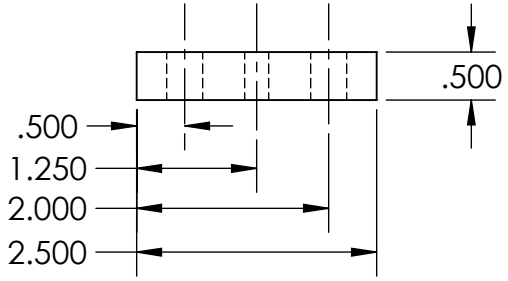
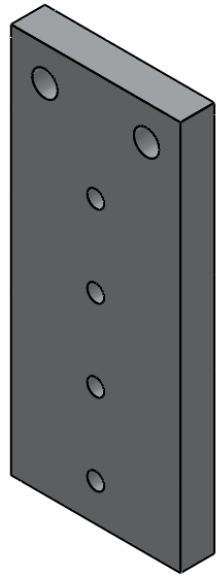
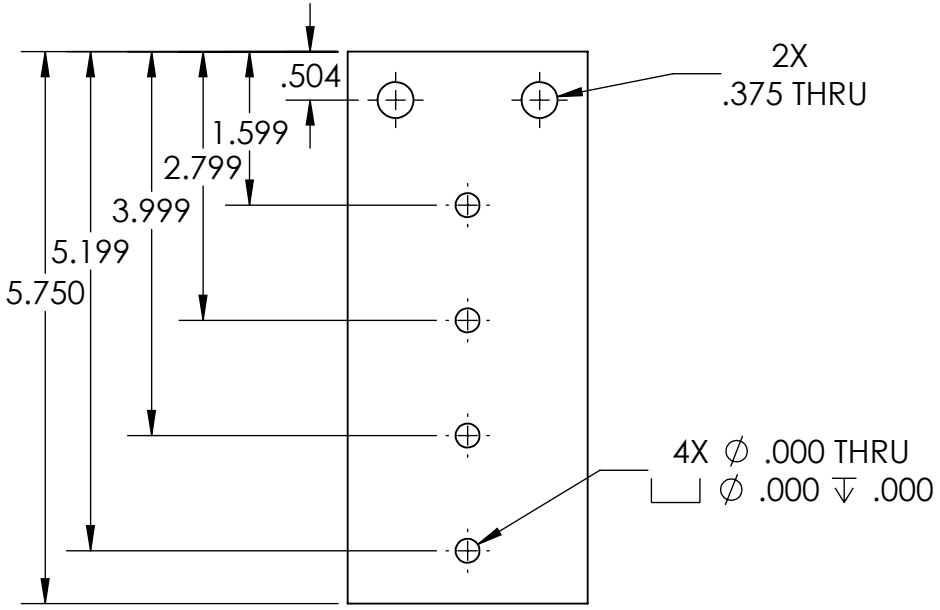
ME DEPARTMENT

PART #: 01-02 QTY: 1
SCALE: 1:5 SHEET: 3 OF 5







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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061-T6 (SS)

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DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0 30'

DESCRIPTION: Motor Track Mount

CHECKED BY: Nicholai Olson DATE: 5/10/2012

DRAWN BY: Cameron Hjeltness DATE: 5/10/2012

FILE NAME: 01-03 Motor Track Mount.SLDPRT

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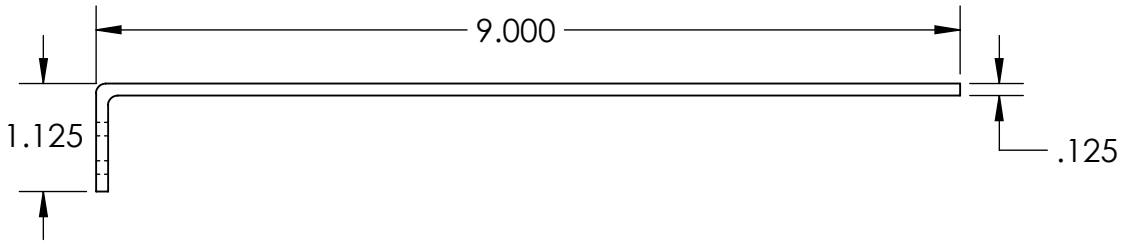
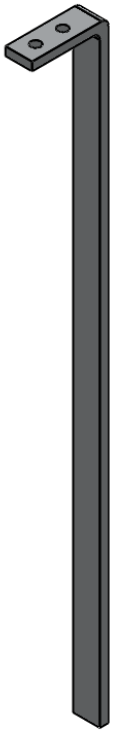
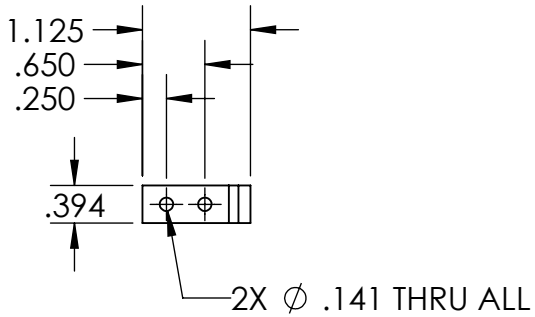
PART #: 01-03 QTY: 1

SCALE: 1:5 SHEET: 4 OF 5







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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 1060 Alloy

DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Encoder Rail
CHECKED BY: Nicholai Olson DATE: 5/10/2012
DRAWN BY: Cameron Hjeltness DATE: 5/10/2012
FILE NAME: 01-04 Encoder Rail.SLDPRT

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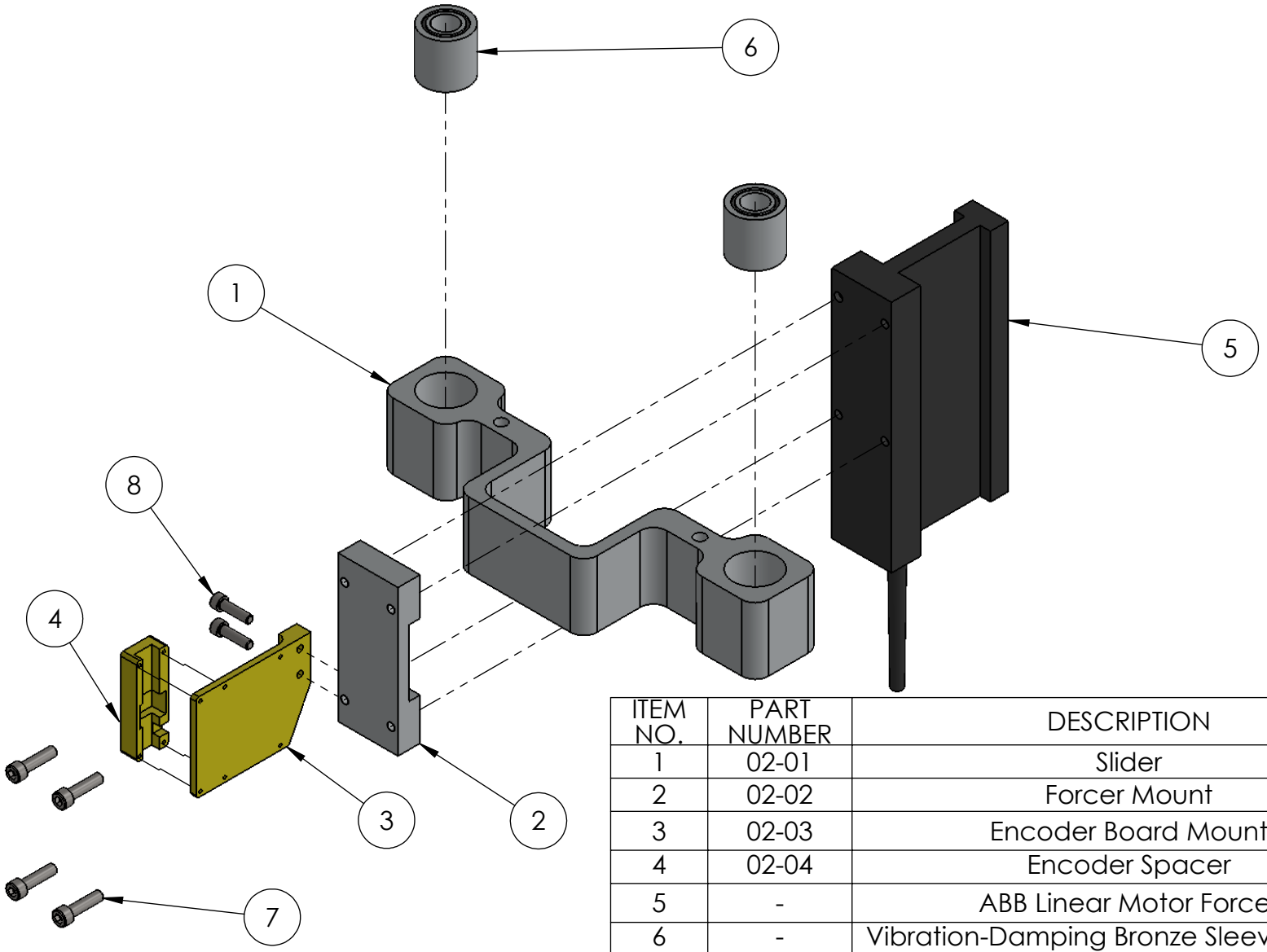
PART #: 01-04 QTY: 1
SCALE: 1:5 SHEET: 5 OF 5



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	SHEET
1	02-01	Slider	1	2
2	02-02	Forcer Mount	1	3
3	02-03	Encoder Board Mount	1	4
4	02-04	Encoder Spacer	1	5
5	-	ABB Linear Motor Forcer	1	-
6	-	Vibration-Damping Bronze Sleeve Bearing	2	-
7	-	HX-SHCS 0.19-32x0.75x0.75-N	4	-
8	-	HX-SHCS 0.164-32x0.625x0.625-N	2	-

Notes: 1) Vibration-Damping Bronze Sleeve Bearings
McMaster-Carr Part No. 6364K32.
2) ABB Linear Motor Forcer Part No. LMCFO4D-HCO.

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Vairous

DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Slider Assembly
CHECKED BY: Nicholai Olson DATE: 5/11/2012
DRAWN BY: Cameron Hjeltness DATE: 5/10/2012
FILE NAME: 02-00 Slider.SLDPRT

SandiaMAST

UNIVERSITY OF IDAHO
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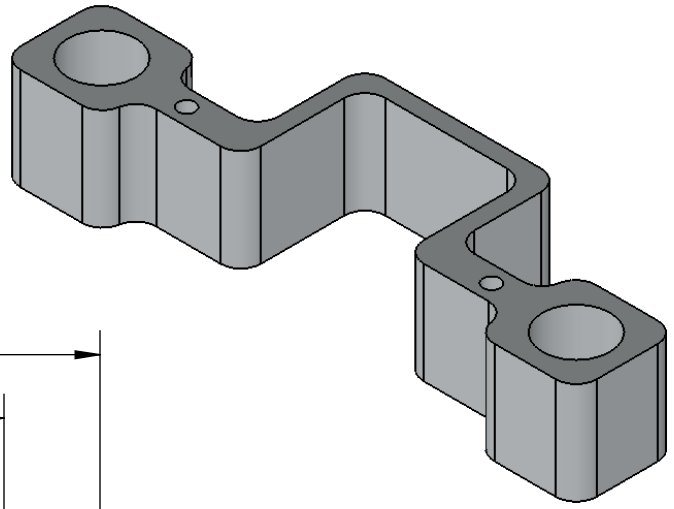
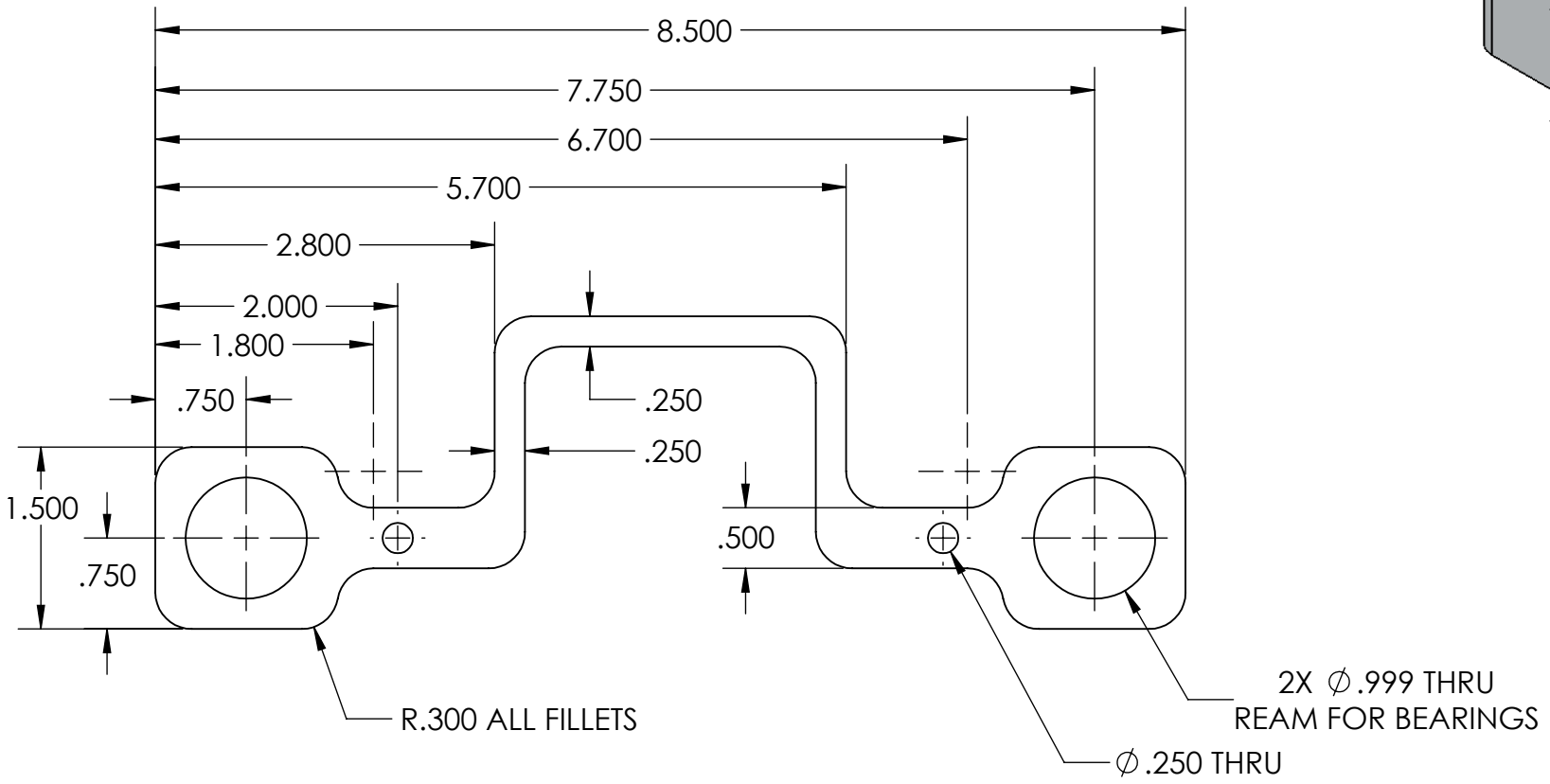
PART #: 02-00 QTY: 1
SCALE: 1:1 SHEET: 1 OF 5





Note: Depth of stock is 1-1/2 inches.

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061-T6 (SS)

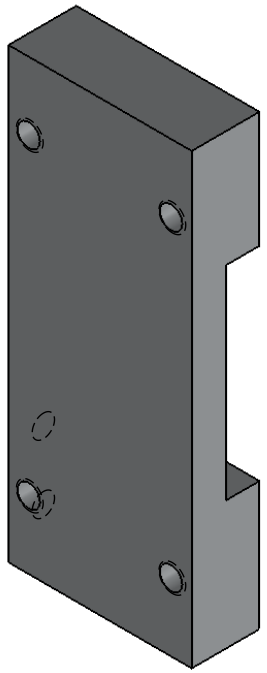
SandiaMAST

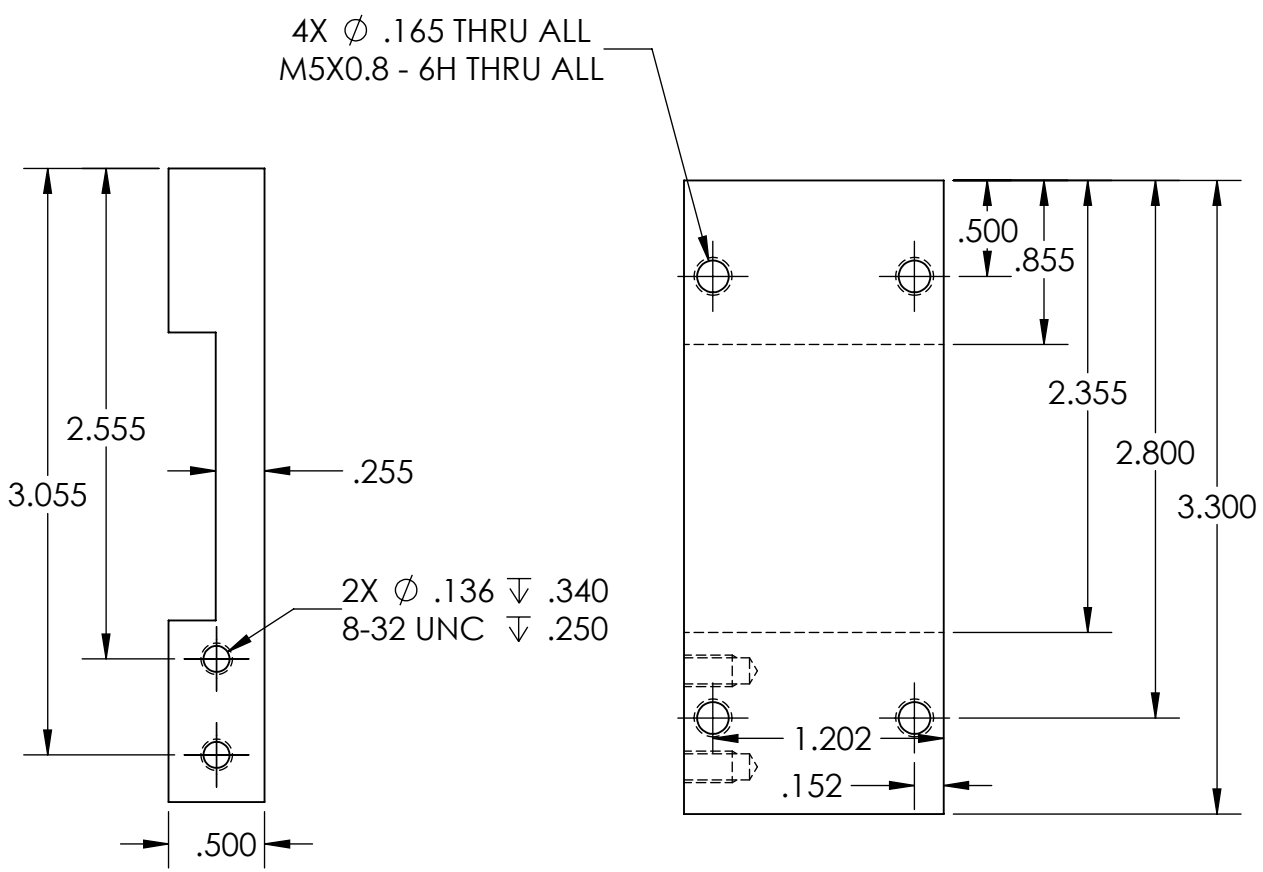
DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Slider
CHECKED BY: Nicholai Olson DATE: 5/11/2012
DRAWN BY: Cameron Hjeltness DATE: 5/9/2012
FILE NAME: 02-01 Slider.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 02-03 QTY: 1
SCALE: 1:2 SHEET: 2 OF 5





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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061-T6 (SS)

DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Forcer Mount
CHECKED BY: Nicholai Olson DATE: 5/11/2012
DRAWN BY: Cameron Hjeltness DATE: 5/10/2012
FILE NAME: 02-02 Forcer Mount.SLDPRT

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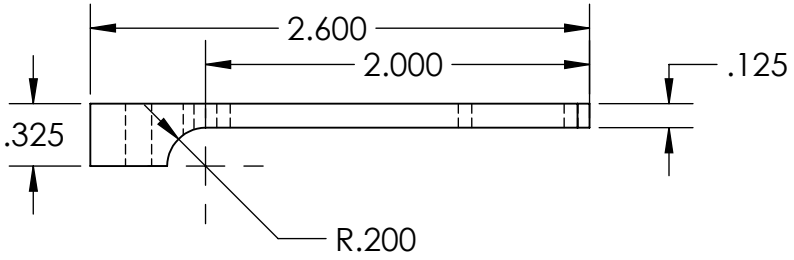
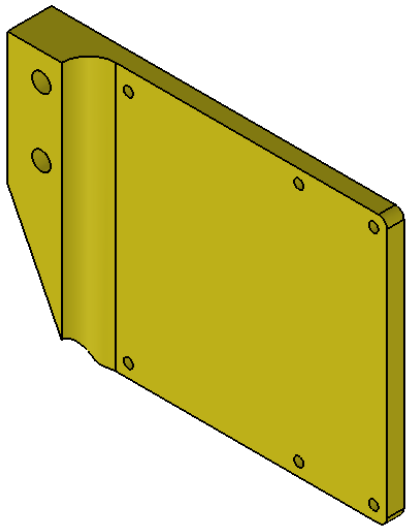
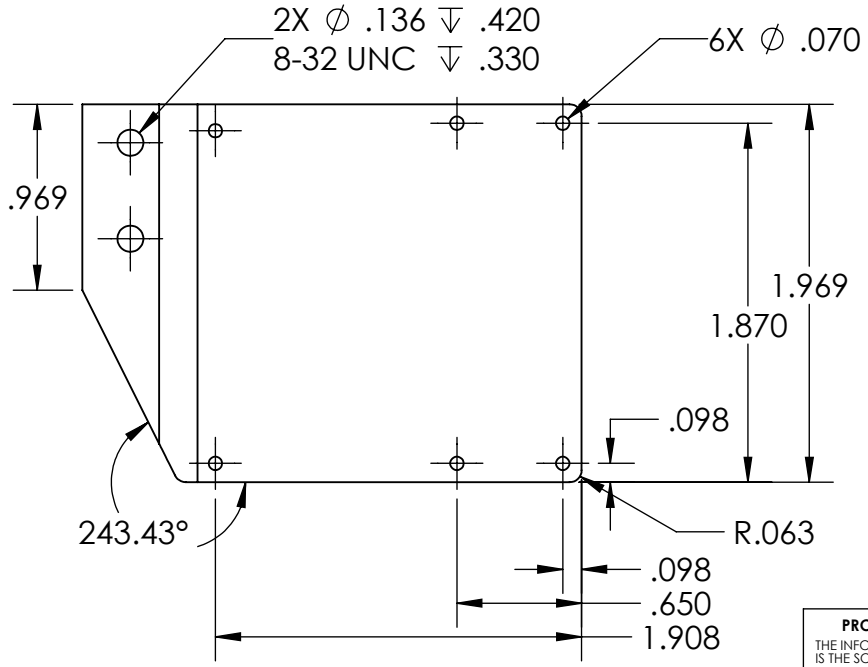
ME DEPARTMENT

PART #: 02-02 QTY: 1
SCALE: 1:1 SHEET: 3 OF 5







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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Printed Plastic

DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Encoder Board Mount
CHECKED BY: Nicholai Olson DATE: 5/11/2012
DRAWN BY: Cameron Hjeltness DATE: 5/9/2012
FILE NAME: 02-03 Encoder Board Mount.SLDPRT

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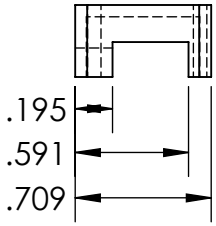
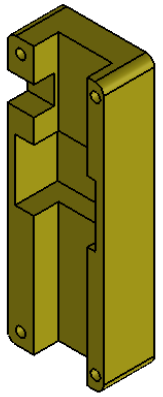
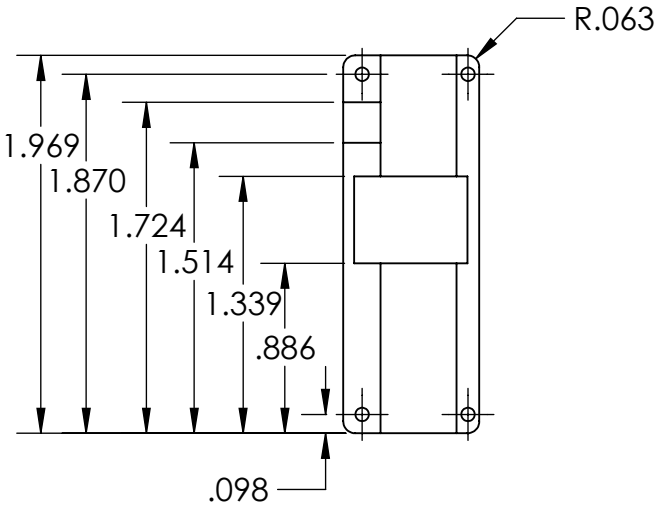
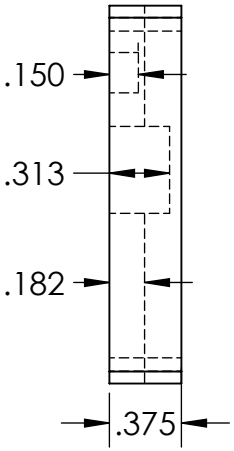
ME DEPARTMENT

PART #: 02-03 QTY: 1
SCALE: 1:1 SHEET: 4 OF 5









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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Printed Plastic

DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Encoder Spacer
CHECKED BY: Nicholai Olson DATE: 5/11/2012
DRAWN BY: Cameron Hjeltness DATE: 5/9/2012
FILE NAME: 02-04 Encoder Spacer.SLDPRT

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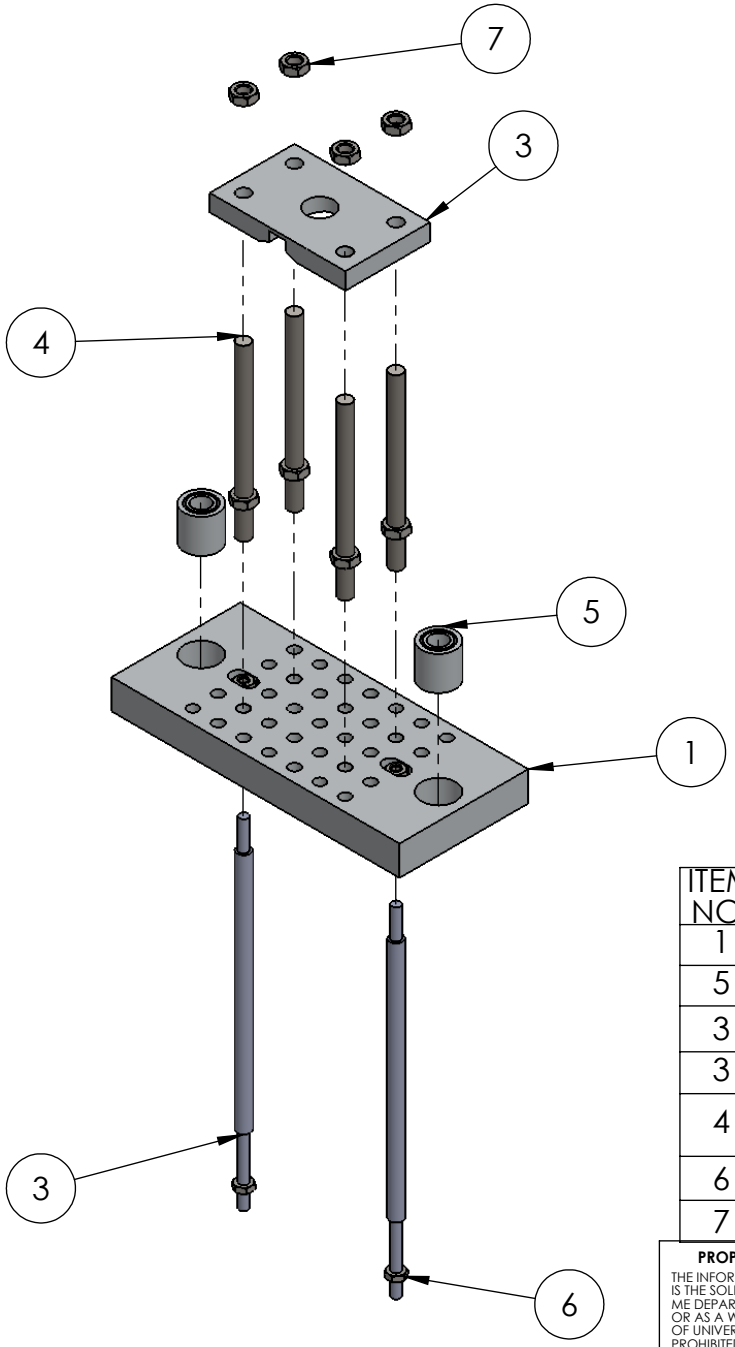
ME DEPARTMENT

PART #: 02-04 QTY: 1
SCALE: 1:1 SHEET: 5 OF 5



Note: Vibration-Damping Bronze Sleeve Bearings
McMaster-Carr Part No. 6364K32

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	Sheet
1	03-01	Drop Table	1	2
5	03-02	Connecting Rod	2	3
3	03-03	Hold Down Fixture	1	4
3	-	3/8-16X5 Fully Threaded Stud	4	-
4	-	Vibration Damping Bronze Sleeve Bearing	2	-
6	-	HJNUT 0.2500-20-D-N	4	-
7	-	HJNUT 0.3750-16-D-N	8	-

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Various

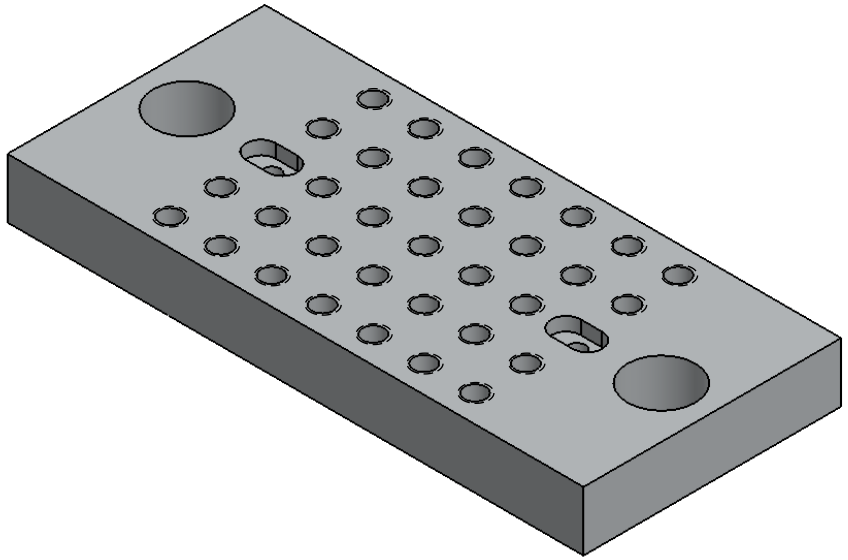
SandiaMAST

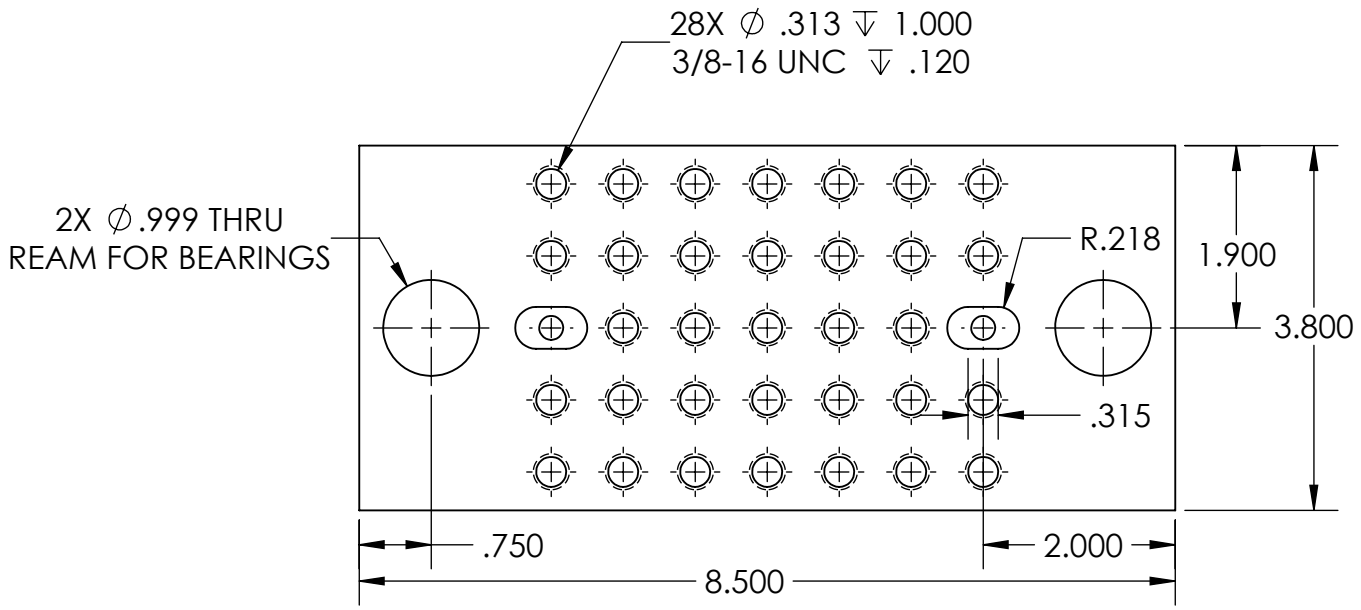
DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Drop Table Assembly
CHECKED BY: Nicholai Olson DATE: 5/11/2012
DRAWN BY: Cameron Hjeltness DATE: 5/10/2012
FILE NAME: 03-00 Drop Table.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 03-00 QTY: 1
SCALE: 1:8 SHEET: 1 OF 4





Notes: 1) Stock 0.875 inches thick.
2) Bolt pattern 1-1/2 inch centers, 3/8-16 UNC threads.

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061-T6 (SS)

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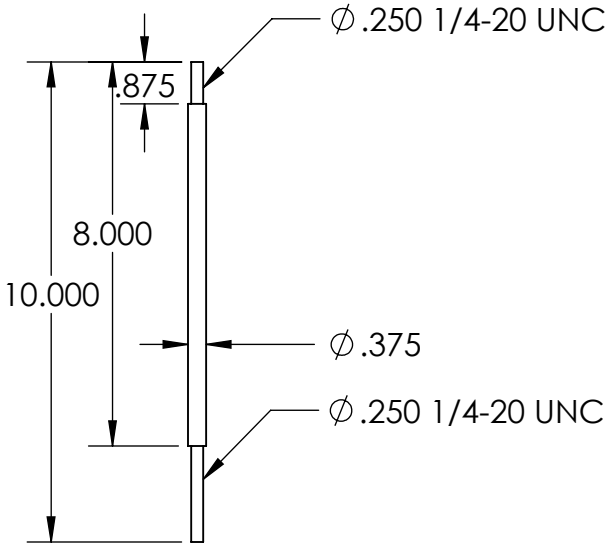
DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Drop Table
CHECKED BY: Nicholai Olson DATE: 5/11/2012
DRAWN BY: Travis Nebeker DATE: 5/10/2012
FILE NAME: 03-01 Drop Table.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 03-01 QTY: 1
SCALE: 1:4 SHEET: 2 OF 4



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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Material <not specified>

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DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0 30'

DESCRIPTION: Connecting Rod

CHECKED BY: Nicholai Olson DATE: 5/11/12

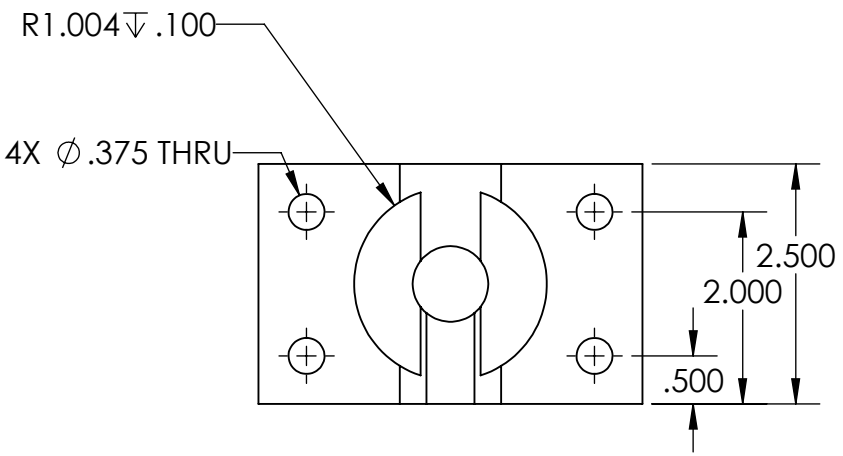
DRAWN BY: Cameron Hjeltness DATE: 5/9/2012

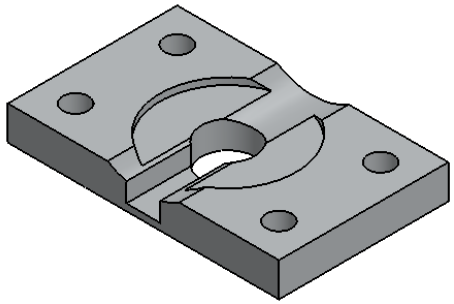
FILE NAME: 03-02 Connecting Rod.SLDPRT

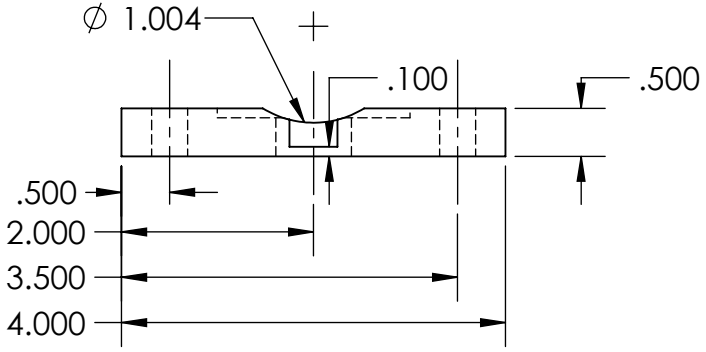
UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 03-02 QTY: 2

SCALE: 1:4 SHEET: 3 OF 4







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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061-T6 (SS)

SandiaMAST

DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ± .25	X. ± 2
X.X ± .1	X.X ± 1
X.XX ± .01	X.XX ± 0 30'
X.XXX ± .002	

DESCRIPTION: 3/8-16 Fully Thread Stud

CHECKED BY: Nicholai Olson DATE: 5/11/12

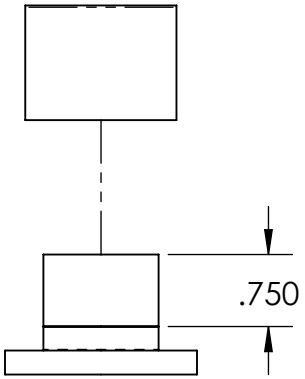
DRAWN BY: Travis Nebeker DATE: 5/10/2012

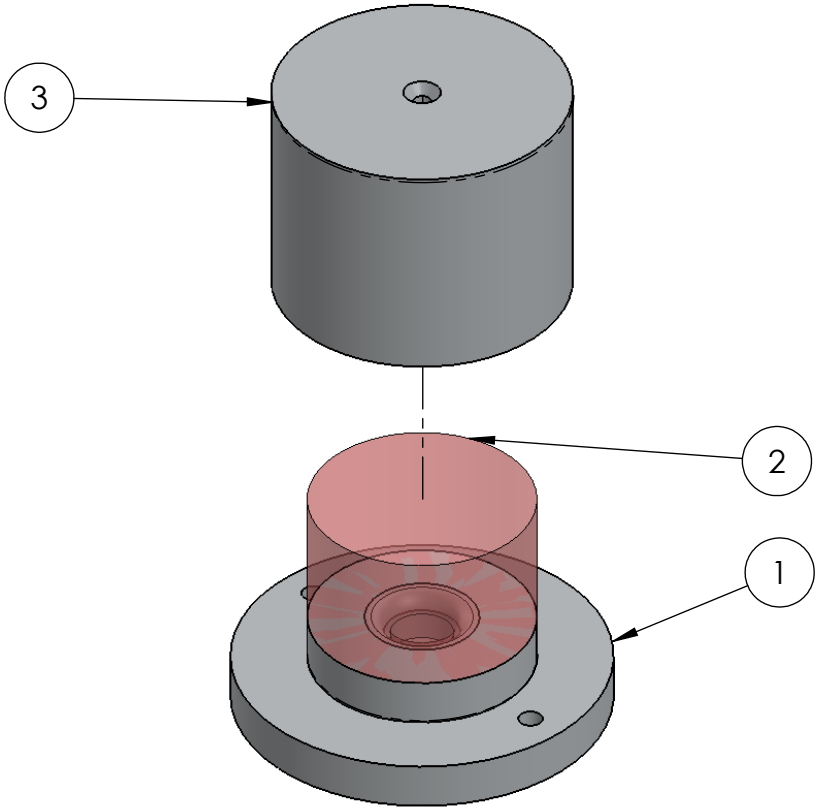
FILE NAME: 03-03 Hold Down Fixture.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 03-03 QTY: 1

SCALE: 1:2 SHEET: 4 OF 4





Note: This assembly is molded using castable polyeurathane materials. Place Dampener Mold Cap over top of Dampener Base and inject materials into opening in bottom. Mold damper to height of 0.750 inches.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	SHEET
1	04-01	Dampener Base	1	2
2	04-03	Damping Material	1	-
3	04-02	Dampener Mold Cap	1	3

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Various

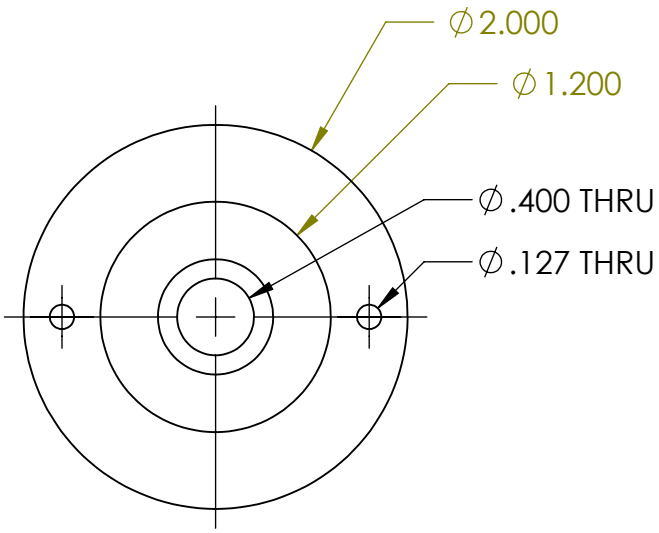
DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

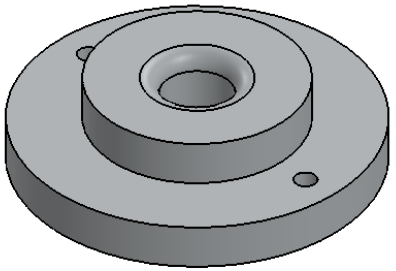
DESCRIPTION: Shock Dampener
CHECKED BY: Nicholai Olson DATE: 5/11/2012
DRAWN BY: Cameron Hjeltness DATE: 5/10/2012
FILE NAME: 04-00 Shock Dampener.SLDPRT

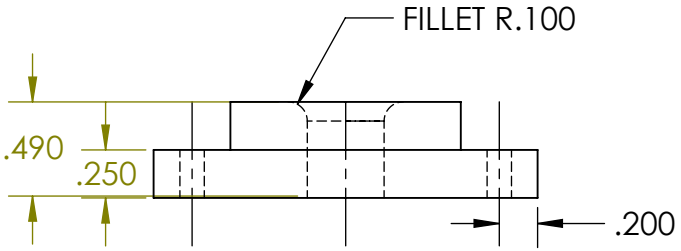
SandiaMAST

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 04-00 QTY: As Necessary
SCALE: 1:2 SHEET: 1 OF 3







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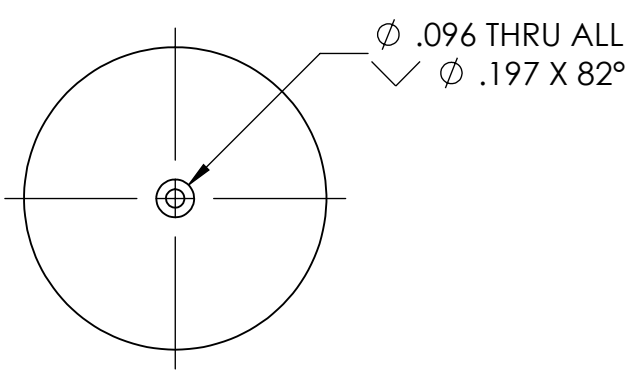
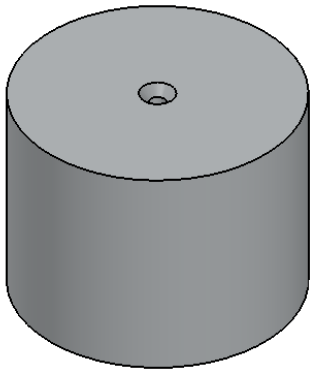
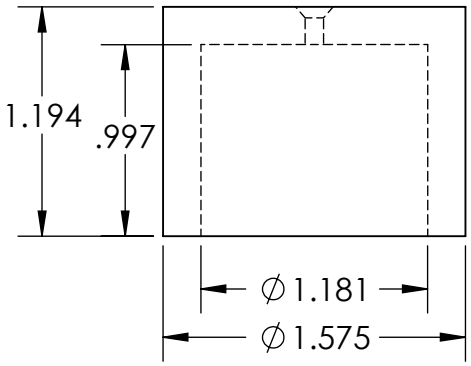
DEFAULT TOLERANCES: LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002 ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'	DESCRIPTION: Dampener Base		**UNIVERSITY OF IDAHO ME DEPARTMENT**
	CHECKED BY: Nicholai Olson	DATE: 5/11/2012	
	DRAWN BY: Cameron Hjeltness	DATE: 5/10/2012	PART #: 04-01 / QTY: As Necessary
	FILE NAME: 04-01 Dampener Base.SLDPRT		SCALE: 1:1 / SHEET: 2 OF 3







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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061 Alloy

SandiaMAST

DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0 30'

DESCRIPTION: Dampener Mold Cap

CHECKED BY: Nicholai Olson DATE: 5/11/2012

DRAWN BY: Cameron Hjeltness DATE: 5/10/2012

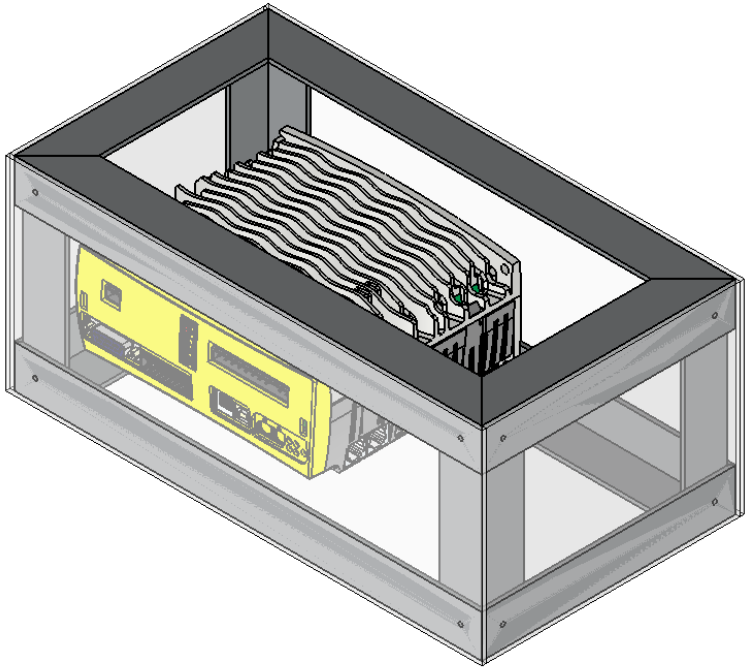
FILE NAME: 04-02 Dampener Mold Cap.SLDPRT

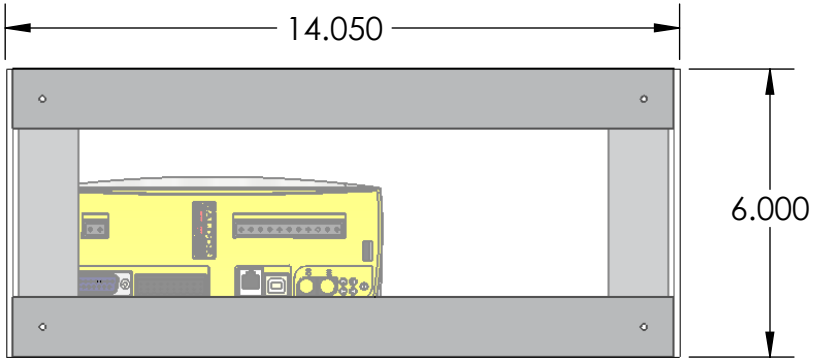
UNIVERSITY OF IDAHO
ME DEPARTMENT

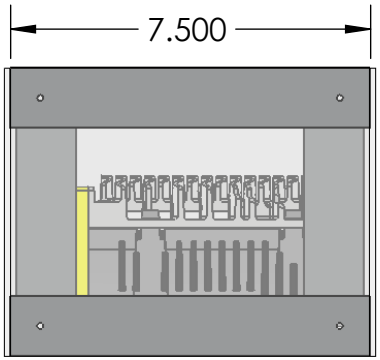
PART #: 04-02 QTY: As Necessary

SCALE: 1:1 SHEET: 3 OF 3

Notes: 1) Construct housing out of 1-1/4 inch 90 degree angle iron.
2) Considerations for fitting and mounting electrical components are necessary.
3) Cover housing with Plexi-glass for safety.
4) ABB MicroFlex e100 Brushless Servo Control Part No. MFE230A003B







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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Various

DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Electrical Housing Assembly
CHECKED BY: Nicholai Olson DATE: 5/11/2012
DRAWN BY: Cameron Hjeltness DATE: 5/10/2012
FILE NAME: 05-00 Electrical Housing.SLDPRT

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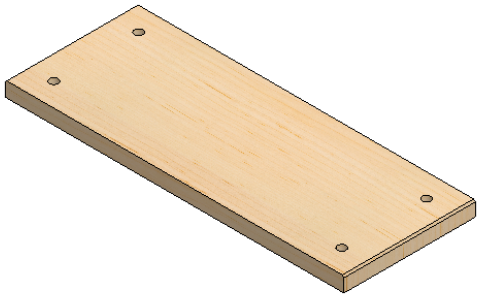
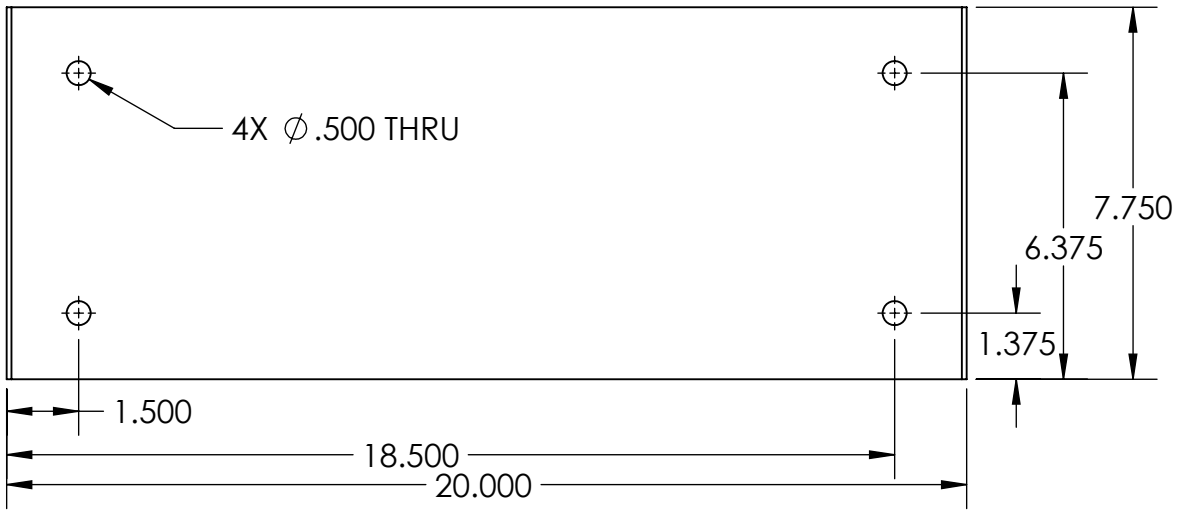
UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 05-00 QTY: 1
SCALE: 1:4 SHEET: 1 OF 1





Note: 1) Use Hickory stock 0.875 inches thick.
2) Attach to Electrical Housing using wood screws.

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Hickory

DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Mounting Base
CHECKED BY: Nicholai Olson DATE: 5/11/12
DRAWN BY: Travis Nebeker DATE: 5/10/2012
FILE NAME: 06-00 Mounting Base.SLDPRT

SandiaMAST

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 06-00 QTY: 1
SCALE: 1:4 SHEET: 1 OF 1